

In vitro assessment of the mechanical properties of latex and non-latex orthodontic elastics

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The increased incidence of latex allergies has led to the development of non-latex orthodontic products. The purpose of this study was to compare the mechanical properties of latex and non-latex orthodontic elastics. The elastics tested were from 2 manufacturers (GAC and Masel) and made of 2 materials (latex and non-latex). The properties tested included cross-sectional area, breaking force, peak load, peak stress, stiffness, modulus, hysteresis, and 24-hour load relaxation. The data were analyzed with 1-sample *t* tests, an analysis of variance, and the Fisher PLSD test. Between GAC and Masel, the GAC non-latex elastics had greater breaking forces than did the Masel non-latex elastics. The Masel latex elastics had greater breaking forces than did the Masel non-latex elastics. The GAC non-latex elastics showed more viscoelastic properties than both the GAC latex elastics and the Masel non-latex elastics; however, the Masel elastics were more viscoelastic than the GAC elastics. Forces generated by the elastics decreased over 24 hours to an average load approximating 75% of the manufacturers' values (GAC latex, Masel latex, and Masel non-latex elastics) and to 60% for the GAC non-latex elastics. The mechanical properties of the non-latex elastics were not comparable to those of the latex elastics. Therefore, the clinical choice of elastics should be based on the patient's medical history and the specific mechanical properties of the type of elastic. (*Am J Orthod Dentofacial Orthop* 2001;120:36-44)

Reactions to latex materials have become more prevalent—and better recognized—since the 1988 adoption of universal precautions.¹ Only 3 reports have been cited in the literature relating latex allergies to orthodontic treatment. Two of these studies related the allergic reactions to the use of latex gloves,^{2,3} and the third report related the development of stomatitis with acute swellings and erythematous buccal lesions to the use of orthodontic elastics.⁴ Most documented allergic reactions to latex products have identified the residual rubber protein as the antigen.^{5,6} Reactions to latex carry with them a wide range of risk, including dermatologic reactions, respiratory reactions, and systemic reactions—in the extreme, anaphylactic

shock.^{7,8} Cutaneous exposure of an individual sensitive to latex frequently causes contact dermatitis, whereas either mucosal or parenteral contact—as with the use of orthodontic elastics—is more likely to induce a rapid systemic reaction such as anaphylactic shock.

As the incidence of latex allergic reactions increases, the use of non-latex products within the orthodontic specialty, as well as the assessment of the material properties of non-latex elastics, will become increasingly important clinically. Two orthodontic companies were marketing non-latex orthodontic elastics at the time of this study. However, to date, there have been no published independent studies that have investigated the mechanical properties of non-latex orthodontic elastics relevant to clinical practice. To our knowledge, the only studies in the literature comparing latex and non-latex orthodontic materials are limited to those that have examined non-latex products such as AlastiK chains (3M Unitek, Monrovia, Calif) (also called plastic modules or power-chain) that are composed of proprietary polyurethane elastomers. Because elastomers rely on entanglements, rather than covalent crosslinks, to limit force relaxation, the mechanical performance of these polyurethane materials has been poor compared with that of latex materials. Clinicians using orthodontic elastics need to know the forces applied to teeth at a given elastic extension and how this force declines over time. Thus, in any comparison between latex and non-latex elastics, the nearly instan-

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Table I. Types of elastics and manufacturer's specified force values

<i>Latex elastics</i>	<i>Non-latex elastics</i>	<i>Manufacturer's specified forces</i>
GAC light	GAC light	76.6 g (2.7 oz)
GAC medium	GAC medium	113.4 g (4 oz)
GAC heavy	GAC heavy	170.1 g (6 oz)
Masel light	Masel light	56.7 g (2 oz)
Masel medium	Masel medium	113.4 g (4 oz)
Masel heavy	Masel heavy	170.1 g (6 oz)

taneous (elastic) force at a given extension and the force relaxation rate over a 24-hour period need to be independently assessed. The clinical guidelines for the use of latex elastics may not necessarily apply to the use of non-latex elastics. Consequently, the material properties of non-latex elastics must be evaluated experimentally and compared with latex materials to develop clinical guidelines for non-latex elastics.

The purpose of this study was to compare the in vitro mechanical properties of latex and non-latex elastics in a clinically relevant environment. The specific aims were to determine the following: (1) the breaking force for each elastic type, (2) the initial forces generated by latex and non-latex orthodontic elastics, and (3) the force relaxation of latex and non-latex orthodontic elastics held at constant extensions for 24 hours.

MATERIAL AND METHODS

Material

Samples of latex and non-latex orthodontic elastics were obtained from GAC International (Islandia, NY) and Masel Enterprises (Bristol, Pa). The elastics were reported to be of 6.25 mm (.25 in) internal diameter (ID) and of light, medium, and heavy weights (Table I). All testing was conducted on 6 samples of each elastic type; thus, there were 72 elastics tested for each specific mechanical test. All elastics were tested as intact loops (ie, uncut).

Methods

The cross-sectional area of each elastic (width and thickness) was measured with the use of a Mitutoyo nonrotating thickness gauge (Model 7309; Mitutoyo, Aurora, Ill). The precision of the gauge itself is ± 0.005 mm under a compressive force of ≈ 1 g.⁹ Measurements were made at 4 locations on 6 elastics of each of the 12 elastic types. The mean cross-sectional area of each elastic was then calculated and used to assess the uniformity of the elastic's morphology; it was also used in the calculations of stress and modulus.

Breaking force tests were performed with an Instron

Table II. Variability in elastics' cross-sectional areas

<i>Elastic</i>	<i>Mean (mm²)</i>	<i>SD (mm²)</i>	<i>Range* (mm²)</i>
GAC latex light	0.67	0.04	0.59–0.75
GAC latex medium	1.00	0.05	0.90–1.10
GAC latex heavy	1.26	0.05	1.16–1.36
GAC non-latex light	0.75	0.03	0.69–0.81
GAC non-latex medium	1.46	0.09	1.28–1.64
GAC non-latex heavy	1.70	0.10	1.50–1.90
Masel latex light	0.51	0.05	0.41–0.61
Masel latex medium	0.98	0.06	0.86–1.10
Masel latex heavy	1.45	0.12	1.20–1.69
Masel non-latex light	0.47	0.03	0.41–0.53
Masel non-latex medium	0.69	0.07	0.55–0.83
Masel non-latex heavy	1.03	0.03	0.97–1.09

*The ranges include 95% of the elastics in a calculated normal distribution around the mean.

Table III. Cross-sectional area comparisons

<i>Elastic type</i>	<i>Comparison</i>
Latex light	GAC > Masel*
Latex medium	NS
Latex heavy	Masel > GAC*
Non-latex light	GAC > Masel*
Non-latex medium	GAC > Masel*
Non-latex heavy	GAC > Masel*
GAC light	NL > L*
GAC medium	L > NL*
GAC heavy	L > NL*
Masel light	NS
Masel medium	L > NL*
Masel heavy	L > NL*

* $P < .05$.

NS, Not significant; L, latex; NL, non-latex.

1000 materials testing machine (Instron, Canton, Mass) at room temperature. The elastics were extended at a cross-head speed of 100 mm/min until failure, at which time the peak failure force was recorded.

Short-term dynamic mechanical tests were conducted in uniaxial mode on a servohydraulic testing system.¹⁰ The servohydraulics were interfaced with a Macintosh Centris 650 computer (Apple Computer, Cupertino, Calif) and custom-written software written under National Instruments' LabVIEW development system (National Instruments, Austin, Tex). Experiments were performed to determine the peak loads generated by elastics when stretched to 2 or 3 times the nominal ID of each elastic type (loading time 0.1 second), for 6 repetitions. The orthodontic elastics were also cyclically extended at a frequency of 1.0 Hz for 50 cycles between the nominal ID and 3 times the ID in room temperature air. The mean data for the last 5 cycles were used to calculate the peak load, peak stress, linear stiffness, tangent modulus, and

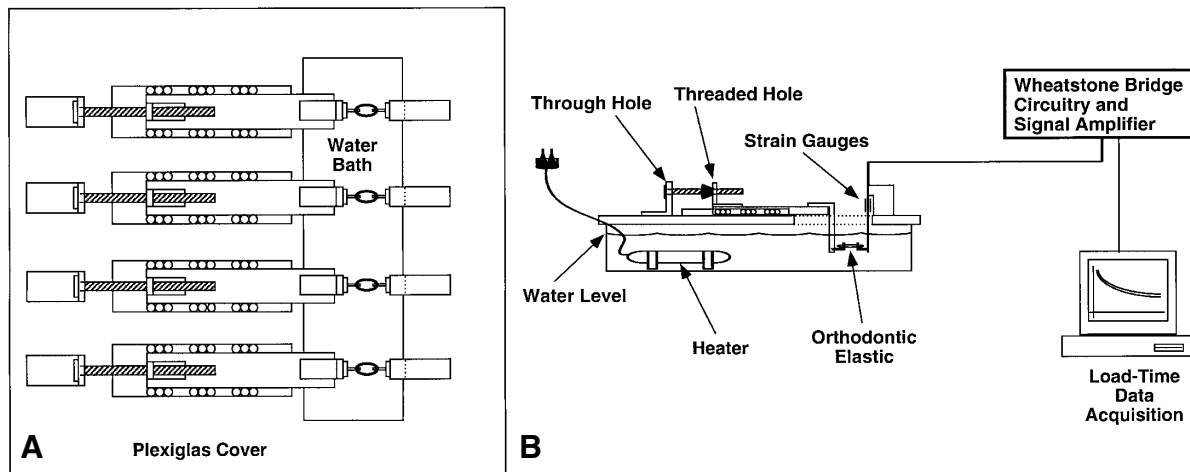


Fig 1. Diagram of custom-made apparatus for 24-hour load relaxation tests with **(A)** superior and **(B)** lateral schematic views. Submerged heater that maintained water bath at 37°C and 4 temperature-compensated strain gauges are shown. Testing system attached to computer that was interfaced to load cells through circuitry to record data measured by strain gauges. Orthodontic elastics were maintained in stretched configuration during testing by adjusting leadscrew through threaded hole until desired load was created.

percent hysteresis between the loading and unloading portions of the testing cycles.

The 24-hour load relaxation mechanical testing was conducted on a custom-built computer-interfaced testing apparatus that was capable of testing 4 samples simultaneously (Fig 1). The elastics were held between hook grips that projected below the testing jig and were submerged in distilled water maintained at 37°C by thermostatically controlled heaters. In less than 5 seconds, each elastic sample was elongated with a leadscrew to an initial extension where the force level equaled that specified by the manufacturer. The forces applied to the elastics were measured with the use of 4 independent temperature-compensated, strain-gauged cantilever load cells that were custom-constructed as described by Lee et al.¹¹ The precision of the force transducers was 0.5 g and 0.05 g for the strain-gauged cantilevers and Transducer Techniques cells respectively.^{11,12} Pairs of load cells were connected to 2 series 700 conditioning amplifiers (RDP Electronics, Wolver Hampton, U.K.) housed in an existing chassis that supplied voltage to the amplifiers. Load and time data were recorded with custom-written LabVIEW software (National Instruments) running on an accelerated Apple MacIntosh IIci computer (Apple Computer) equipped with a 12-bit A/D data acquisition board (National Instruments). The constant extension of the elastics was maintained for 24 hours while force-time data were collected at 15-minute intervals over the 24-hour period.

Statistical methods

The cross-sectional area data were analyzed by using an analysis of variance (ANOVA) and the Fisher PLSD test. The means and SDs for the cross-sectional area data were reported to illustrate the wide variance in the data. The breaking force and load relaxation data were analyzed by material type (latex vs non-latex) and by manufacturer (Masel vs GAC) with an ANOVA and the Fisher PLSD test for multiple comparisons. The mean and SDs of the force values generated at 2 and 3 times extensions were calculated and descriptively compared with the manufacturers' specified load values. Comparisons were also made between the loads maintained by the elastics at 1, 6, 12, and 24 hours and the manufacturers' specified load values with a 1-sample *t* test. Three-way comparisons among light-, medium-, and heavy-weight elastics were completed for the GAC latex, GAC non-latex, Masel latex, and Masel non-latex elastics with a 3-way ANOVA and the Fisher PLSD test. All statistical analyses were conducted with StatView 4.5 software (SAS Institute, Cary, NC) on a G3 Macintosh computer (Apple Computer). The level of statistical significance was $P < .05$.

RESULTS

For all elastic types (GAC latex, GAC non-latex, Masel latex, and Masel non-latex), the heavy elastics had larger cross-sectional areas than did the medium elastics, and the medium elastics had larger cross-sectional areas than did the light elastics.

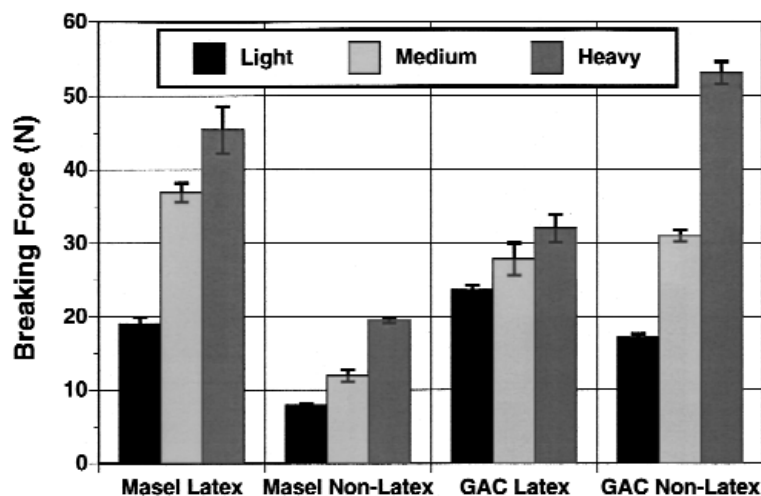


Fig 2. Bar graph shows *breaking forces* of GAC and Masel latex and non-latex elastics. Comparisons between breaking forces of 3 weights of elastics illustrate that heavier elastics have greater breaking forces than do lighter-weight elastics. Difference in material properties for latex and non-latex elastics between Masel and GAC is also shown. *GAC non-latex* elastics have greater breaking forces than do *Masel non-latex*. *Masel latex* elastics have greater breaking forces than do *Masel non-latex* elastics. This was not seen for *GAC non-latex* elastics, where some non-latex elastics were stronger than latex.

tional areas than did the light elastics (Table II). The mean cross-sectional areas had surprisingly wide variability. Table II reports the mean and SDs of the cross-sectional areas for each elastic type, as well as the range of cross-sectional areas encompassing 95% of the elastics. There were significant differences in the elastics' cross-sectional areas between the 2 manufacturers as well as between the latex and non-latex materials (Table III). When all 3 weights of elastics were compared, only the non-latex elastics showed any consistent relationship, such that all the non-latex GAC elastics had larger cross-sectional areas than the non-latex Masel elastics (Table III).

There were 2 consistent relationships for the breaking forces of the elastics. The Masel latex elastics had greater breaking forces than the Masel non-latex elastics for all 3 elastic weights, and the GAC non-latex elastics had greater breaking forces than the Masel non-latex elastics (Table IV, Fig 2). No consistent trends in breaking force were observed between the GAC latex and non-latex elastics or between the Masel and GAC latex elastics (Table IV).

The loads generated by the elastics when they were stretched to 2 and 3 times the ID are listed in Table V. When stretched to 2 times the ID, the elastics generated forces lower than or equal to the manufacturers' specified values, whereas, when the elastics were stretched to 3 times the ID, the forces generated were larger than or equal to the manufacturers' specified values.

Table IV. Ultimate tensile strength comparisons

Elastic type	Comparison
Masel light	L > NL*
Masel medium	L > NL*
Masel heavy	L > NL*
GAC light	L > NL*
GAC medium	NS
GAC heavy	NL > L*
Non-latex light	GAC > Masel*
Non-latex medium	GAC > Masel*
Non-latex heavy	GAC > Masel*
Latex light	GAC > Masel*
Latex medium	Masel > GAC*
Latex heavy	Masel > GAC*

* $P < .05$.

NS, Not significant; L, latex; NL, non-latex.

The results of the short-term dynamic mechanical testing showed significant differences by elastic material and manufacturer (Table VI). The comparisons between the GAC and Masel latex elastics were variable with only the moduli of all 3 weights of the Masel latex elastics being significantly higher than those for the corresponding GAC latex elastics. For all weights of the non-latex elastics, the peak stress, modulus, and hysteresis values were larger for the Masel than for the GAC non-latex elastics. All the significant differences between the material properties for both the latex and

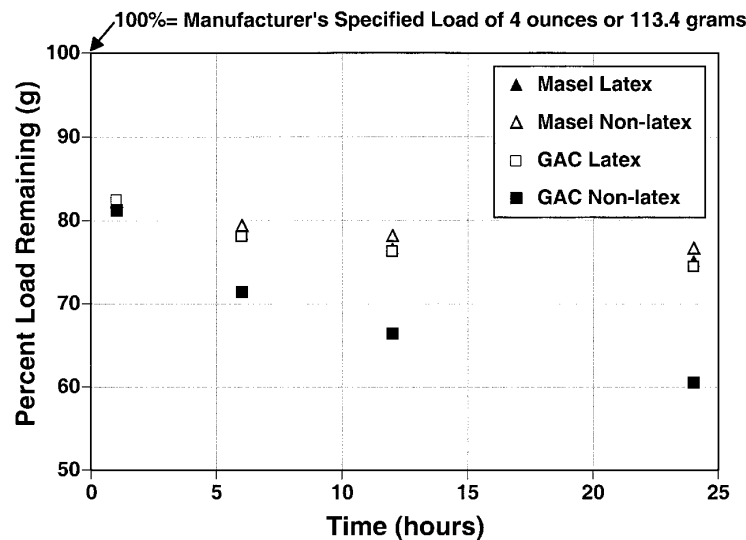


Fig 3. Decreases in loads maintained over 24 hours of typical 4 oz (medium) elastic are shown on graph. Loads at 1 hour are significantly less than *manufacturer's specified loads* and continue to decrease over 24-hour test. Loads remaining in *GAC non-latex* elastics were significantly lower than for other 3 types of elastics from 6 to 24 hours. Standard errors for loads were smaller than symbols used in graph.

Table V. Load values generated at 2 and 3 times the internal diameter (ID)

Elastic and manufacturer's specification	Load at $2 \times ID$ (g)	SD	Load at $3 \times ID$ (g)	SD
GAC latex light (76.6 g or 2.7 oz)	51.5*	6.1	94.4*	8.2
GAC latex medium (113 g or 4 oz)	74.9*	3.4	140.7*	8.5
GAC latex heavy (170 g or 6 oz)	86.0*	5.4	168.7	9.4
GAC non-latex light (76.6 g or 2.7 oz)	47.8*	2.6	78.3	2.9
GAC non-latex medium (113 g or 4 oz)	82.1*	6.7	135.5*	9.7
GAC non-latex heavy (170 g or 6 oz)	117.0*	7.1	198.8*	8.2
Masel latex light (57 g or 2 oz)	45.3*	4.2	81.7*	6.2
Masel latex medium (113 g or 4 oz)	74.3*	13.5	134.4	20.4
Masel latex heavy (170 g or 6 oz)	106.0*	4.4	191.9*	7.0
Masel non-latex light (57 g or 2 oz)	52.3	9.5	109.1*	14.7
Masel non-latex medium (113 g or 4 oz)	77.1*	11.2	155.1*	16.9
Masel non-latex heavy (170 g or 6 oz)	111.3*	21.9	215.4*	13.4

*Significantly different from the manufacturer's value at $P < .05$.

non-latex elastics showed larger values for the Masel elastics (compared with the GAC elastics).

Comparisons between the GAC latex and non-latex elastics were inconsistent (Table VI). The material properties for the Masel latex and non-latex elastics were somewhat more systematic; the values for the Masel non-latex elastics were greater than for the Masel latex elastics except for the peak load and stiffness values for the medium elastics, which were not significantly different. For all 3 weights of both the GAC and Masel elastics, the non-latex elastics showed a greater hysteresis than the latex elastics.

Differences between the percent loads remaining at 1, 6, 12, and 24 hours and the manufacturers' specified

loads were determined for all types of elastics (Table VII). For the load relaxation from 1 hour through 24 hours, there were no consistent similarities between the GAC latex and Masel latex elastics. The Masel non-latex elastics consistently maintained greater loads than the GAC non-latex elastics except at 1 hour, when the medium and heavy elastics produced the same force levels. The GAC latex elastics maintained greater loads than the GAC non-latex elastics from 1 hour through 24 hours except for the light- and medium- weight elastics that were not significantly different at 1 hour. All the Masel non-latex elastics retained larger forces than Masel latex elastics, except for the medium and heavy elastic loads at 1 hour that did not significantly differ. Thus, GAC latex

Table VI. Short-term dynamic mechanical test comparisons

Elastic	Peak load	Peak stress	Modulus	Stiffness	Hysteresis
Latex light	NS	Masel > GAC*	Masel > GAC*	NS	NS
Latex medium	Masel > GAC*	Masel > GAC*	Masel > GAC*	Masel > GAC*	Masel > GAC*
Latex heavy	Masel > GAC*	NS	Masel > GAC*	Masel > GAC*	Masel > GAC*
Non-latex light	Masel > GAC*	Masel > GAC*	Masel > GAC*	Masel > GAC*	Masel > GAC*
Non-latex medium	NS	Masel > GAC*	Masel > GAC*	NS	Masel > GAC*
Non-latex heavy	NS	Masel > GAC*	Masel > GAC*	NS	Masel > GAC*
GAC light	NS	L > NL*	L > NL*	NL > L*	NL > L*
GAC medium	NL > L*	L > NL*	NS	NL > L*	NL > L*
GAC heavy	NL > L*	L > NL*	L > NL*	NL > L*	NL > L*
Masel light	NL > L*	NL > L*	NL > L*	NL > L*	NL > L*
Masel medium	NS	NL > L*	NL > L*	NS	NL > L*
Masel heavy	NL > L*	NL > L*	NL > L*	NL > L*	NL > L*

* $P < .05$.

NS, Not significant; L, latex; NL, non-latex.

Table VII. Twenty-four-hour load relaxation comparisons

Elastic	% Load at 1 hour	% Load at 6 hours	% Load at 12 hours	% Load at 24 hours
Latex light	NS	Masel > GAC*	Masel > GAC*	Masel > GAC*
Latex medium	NS	GAC > Masel*	NS	NS
Latex heavy	GAC > Masel*	GAC > Masel*	GAC > Masel*	GAC > Masel*
Non-latex light	Masel > GAC*	Masel > GAC*	Masel > GAC*	Masel > GAC*
Non-latex medium	NS	Masel > GAC*	Masel > GAC*	Masel > GAC*
Non-latex heavy	NS	Masel > GAC*	Masel > GAC*	Masel > GAC*
GAC light	NS	L > NL*	L > NL*	L > NL*
GAC medium	NS	L > NL*	L > NL*	L > NL*
GAC heavy	L > NL*	L > NL*	L > NL*	L > NL*
Masel light	NL > L*	NL > L*	NL > L*	NL > L*
Masel medium	NS	NL > L*	NL > L*	NL > L*
Masel heavy	NS	NL > L*	NL > L*	NL > L*

* $P < .05$.

NS, Not significant; L, latex; NL, non-latex.

elastics produced larger loads than GAC non-latex elastics, whereas the opposite was true for Masel elastics, where the Masel non-latex elastics generated larger loads than the latex elastics. In a general summary, the relationships between percent loads over the 24-hour time period were as follows: Masel non-latex > GAC non-latex, GAC latex > GAC non-latex, Masel non-latex > Masel latex, and Masel latex = GAC latex.

The relationships between the light, medium, and heavy elastics were highly variable for both the dynamic and the 24-hour load relaxation properties for all elastic types. There were only 2 consistent relationships. The loads retained at 1, 6, 12, and 24 hours by the Masel non-latex elastics showed similar trends; the light elastics retained a greater percent load than the medium, the light elastics retained a greater percent load than the heavy, and the medium retained the same percent load as the heavy elastics (Table VIII). Additionally, all of the percent loads remaining for the Masel light,

medium, and heavy latex elastics were equal at 1 hour, 6 hours, and 12 hours but they varied at 24 hours.

The peak loads from the dynamic relaxation testing and the loads at 1, 6, 12, and 24 hours from the 24-hour load relaxation were significantly lower than the manufacturers' specified values for all elastics except for the peak load of the non-latex Masel light elastics, which did not significantly differ from the manufacturer's specified values (Table IX). The initial peak loads from the dynamic testing were between 50% and 90% of the manufacturers' values. The percent loads dropped from between 80% to 85% at 1 hour to 57% to 80% at 24 hours. The percent loads remaining at the various time intervals for the medium-weight elastics are shown in Figure 3.

DISCUSSION

The media in which elastics have been tested vary considerably. As early as 1939, Paulich¹³ noted that the initial force decay of elastics depended on the environ-

Table VIII. Twenty-four-hour load relaxation comparisons; light vs medium vs heavy elastics*

Elastic	% Load at 1 hour	% Load at 6 hours	% Load at 12 hours	% Load at 24 hours
GAC latex	H > L, L = M, M = H	H > L, M > L, H = M	H > M > L	H > M > L
GAC non-latex	H = M = L	H > L, M > L, H = M	H > L, M > L, H = M	H > L, M > L, H = M
Masel latex	H = M = L	H = M = L	H = M = L	H > L, M > L, H = M
Masel non-latex	L > M, L > H, M = H	L > M, L > H, M = H	L > M, L > H, M = H	L > M, L > H, M = H

*All values are significant at the $P < .05$ level.

H, Heavy; M, medium; L, light.

Table IX. Comparison of mean experimental loads with manufacturer's specified load values*

Elastic	% Peak Load	% Load 1 hour	% Load 6 hours	% Load 12 hours	% Load 24 hours
GAC L Light	63	80	75	72	69
GAC NL Light	50	80	69	63	57
Masel L Light	80	82	78	75	73
Masel NL Light	NS - 93	85	84	82	80
GAC L Medium	57	83	78	76	75
GAC NL Medium	76	81	71	66	61
Masel L Medium	65	82	78	77	75
Masel NL Medium	72	82	79	78	77
GAC L Heavy	70	85	81	79	78
GAC NL Heavy	62	81	72	67	61
Masel L Heavy	70	82	78	77	75
Masel NL Heavy	51	82	79	78	77

*All values are significantly different from the manufacturer's specified loads at $P < .0001$. NS,

Not significant; L, latex; NL, non-latex.

ment in which the elastics were tested. Ash and Nikolai¹⁴ also suggested that greater force relaxation was observed in water at 37°C compared with air at the same temperature. In contrast, Bales et al¹⁵ reported no difference between the forces exerted by orthodontic latex elastics in wet and dry environments. In an oft-cited (but never published) pilot study, Andreasen and Bishara¹⁶ found that room temperature water adequately simulated saliva at 37°C for the assessment of latex elastics, but not for polyurethane elastomer chains. Overall, elastics and non-latex chains have been tested at room temperature and at 37°C, in dry air and moist air, in distilled water, normal saline, and artificial saliva, and with or without aging. However, no consensus on the appropriate conditions for the testing of orthodontic elastics has emerged.

In this study, the short-term dynamic mechanical testing was completed in room temperature air while the 24-hour mechanical testing was conducted in distilled water at 37°C. Clinically, elastics are not aged in a specific medium before use. Rather, they are placed in the mouth (extended between teeth) immediately after removal from a package stored at room temperature. Thus, the dynamic short-term testing was conducted in room temperature air. In a clinical situation

over 24 hours, elastics would reach equilibrium at body temperature of $\approx 37^\circ\text{C}$, so the 24-hour load relaxation testing was conducted in 37°C distilled water to reproduce the clinical situation.

Independent studies have demonstrated that clinically significant discrepancies exist between manufacturers' specified loads and the actual mechanical behavior of the elastics. For example, Bales et al¹⁵ reported that the force exerted at the manufacturer's recommended extension of 3 times the ID was greater than that stated by the manufacturer. They reported that extensions of only 2 times the ID gave more clinically appropriate force levels. There is not, however, an abundance of literature to support this claim, so experiments were completed to assess loads generated when the elastics were stretched to 2 and 3 times the ID (Table V). In general, the loads at 3 times the ID were larger than the manufacturer's values and those at 2 times the ID were smaller than the manufacturer's specified loads. The manufacturer's force values are reported as 2.7 oz or 4 oz with 1 or 2 significant digits, thus claiming a precision no greater than 0.5 and 0.05 oz, respectively. When the experimental values were compared with the reported ones with these precision limits, the results were identical to the results of the statistical analyses except for the Masel medium latex elastics at 3 times the ID stretch. For this type of elastic, there was no statistical difference; however, the value at 3 times the ID did exceed the precision limits implied by the manufacturer. Clinically, if there is a choice between placing an elastic with an unknown force that is higher than the specified value, as opposed to lower, the clinician would most likely choose the lower value because of the clinical ramifications of the use of an unknown large force. Thus, the elastics in this study were stretched to twice their ID for the dynamic load relaxation testing—an approach supported by common clinical recommendations, the present study, and work dating back to Bales et al.¹⁵

There were only 2 consistent statistical trends for the breaking forces of the elastics. The GAC non-latex elastics were stronger than the Masel non-latex elastics, and the Masel latex elastics were stronger than the

Masel non-latex. There are no international standards for the mechanical properties of orthodontic elastics or elastomeric materials. However, there are Australian standards for latex orthodontic elastic bands that state that the breaking strength of the elastics must be greater than 150 kPa, and the extensions at which failures occur must be at least 750% of the resting ID.¹⁷ All of the elastics, both latex and non-latex, and GAC and Masel, met the Standards Association of Australia specifications for both breaking strength and extension. Thus, according to the Standards Association of Australia, all of the elastics were strong enough and extendable enough to meet clinical requirements.

There was a general overall trend for cross-sectional areas to vary according to weight. The heavy elastics had larger cross-sectional areas than did the medium elastics, and the medium elastics had larger areas than did the light elastics. However, the cross-sectional areas of the elastics were highly variable within the individual groups. This variation could have clinical ramifications. Theoretically, for a given material, a larger cross-section generates more force at a given constant extension. Therefore, elastics of the same nominal weight that have larger cross-sectional areas (and therefore larger apparent stiffnesses) will generate greater forces when stretched between 2 teeth. Thus, the wide variability in the cross-sectional area of elastics may translate clinically into forces being placed on teeth that differ significantly and inconsistently from that expected. Whether the forces are larger or smaller than expected depends upon the cross-sectional area of the individual elastic.

The stress values calculated in this study represent the stress values in the elastics (a property of the material) and not the stresses experienced by the teeth that have elastics attached to them. However, the loads reported in this study are equivalent to the forces teeth would experience when elastics are attached to them. Furthermore, a molar tooth would experience a lower stress level from a given force applied by an elastic compared with an anterior tooth because of the molar's larger cross-sectional area. Thus, when choosing an elastic for a given clinical situation, a tooth's cross-sectional area, as well as the force applied by a specific type of elastic, should be considered. The results of this study indicate that the forces generated by the elastics depend on the manufacturer and material type, are not consistent for elastic weights from various manufacturers, and do not consistently equal the loads specified by the manufacturers over a 24-hour load decay.

The term *elastic* is a misnomer because any soft polymeric material, even a well-cross-linked rubber, will display some viscoelastic behavior. Previous stud-

ies of latex elastics reported low cyclic hysteresis (loss of energy) and force relaxation over time (fall in load under constant extension).¹⁸⁻²⁰ The present study confirms these characteristics; furthermore, all the non-latex elastics showed greater hysteresis than did the latex elastics, and all the Masel elastics had greater or equal hysteresis than did the GAC elastics. Bishara and Andreassen²¹ observed a similar result with non-latex polyurethane chains demonstrating more hysteresis and more plastic deformation than the latex elastics. As elastics are stretched, *reversible* uncoiling and extension of polymer molecules, as well as *irreversible* slippage of molecules past one another, occur.²² The irreversible slippage of polymer molecules contributes primarily to the plastic or viscoelastic behavior, and thus the non-latex and Masel elastics may have had more slippage at the molecular level.

Force decay in orthodontic elastics has been well documented. Bales et al¹⁵ cited Bertram in 1931 as having first reported that one third of an elastic's developed force is lost per day and further suggested that, clinically, elastics should be changed on a daily basis. When stretched to twice the ID, 11 of the 12 types of elastics retained mean force values that were significantly less than the manufacturers' specified values, and the forces further decreased over 24 hours. The data from the present study thus support that of Bales et al.¹⁵

In addition to a decrease in force with time, independent studies have reported that non-latex chains had an almost 3 times greater decrease in force than did latex elastics over 24 hours—even though the initial force at a given extension was greater for the chains.^{21,23} The results of this study were less consistent because not all the non-latex materials showed greater load decreases than the latex elastics during the 24-hour load relaxation test. The only constant characteristic was that the ranges of forces for the non-latex elastics were larger than for the latex elastics. The difference in structure between non-latex chains and non-latex elastics may explain the differences in properties that were reported in the 2 studies.

CONCLUSIONS

The use of non-latex orthodontic elastics is required in patients with known latex sensitivities and will likely become more common if the incidence of latex sensitivities continues to rise. However, the mechanical properties of non-latex elastics cannot be assumed to be—and indeed are not—the same as those of latex elastics. The mechanical properties of the elastics varied considerably with the type of material, as well as with the manufacturer, so there are few general conclusions that can be drawn and applied clinically to all

elastic types. Although all of the elastics met the Australian Standards for breaking force, there was a trend toward non-latex elastics having lower breaking forces than the latex elastics. The GAC non-latex elastics lost more energy and retained lower force values than did the GAC latex and the Masel latex and non-latex elastics over time and would likely become less effective to move teeth. Over 24 hours, there was a decrease in the loads generated by all elastics. However, the Masel non-latex elastics retained larger loads than the Masel latex, the GAC latex retained larger loads than the GAC non-latex, and the Masel non-latex retained larger loads than the GAC non-latex elastics. The mean loads generated at the end of 24 hours were similar for GAC latex, Masel latex, and Masel non-latex elastics at $\approx 75\%$ of the manufacturers' values, whereas the GAC non-latex elastics retained only 60% of the manufacturer's values. These results emphasize the importance of choosing elastics based on the clinical situation, as well as the mechanical properties of the elastics that have been shown to vary with material and manufacturer.

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