European Journal of Orthodontics 34 (2012) 202–207
doi:10.1093/ejo/cjq188
Advance Access Publication 13 January 2011

In vitro study of force decay of latex and non-latex orthodontic elastics

Noelia López*, Ascensión Vicente*, Luis A. Bravo*, José L. Calvo** and Manuel Canteras***

*Orthodontic Teaching Unit, Dental Clinic, **Integral adult dentistry Unit, Dental Clinic and ***Department of Biostatistics, Faculty of Medicine, University of Murcia, Murcia, Spain

Correspondence to: Ascensión Vicente, Orthodontic Teaching Unit, Dental Clinic, The University of Murcia, Hospital Morales Meseguer, 2ª planta, C/. Marqués de los Vélez, s/n., 30008 Murcia, Spain. E-mail: ascenvi@um.es

SUMMARY The aim of this study was to evaluate the force decay of two brands of orthodontic elastics, both offering latex and non-latex products. Samples were subjected to continuous stretching, measuring force at 5 seconds, 8 hours, and 24 hours in both dry and wet conditions. Five hundred samples were used, GAC® and Lancer® 0.25 inch and 4 oz, divided into testing sample sizes of n = 25 per group. For the dry test, elastics were kept stretched to three times their internal diameter for 5 seconds (initial force), 8 hours, and 24 hours; for the wet test, they were stretched for 8 and 24 hours. Both brands showed initial forces significantly greater than those specified by the manufacturers ($P < 0.05$). Comparing wet/dry conditions, there was a greater force loss in the wet medium than the dry. As for elastic composition (latex or non-latex), the only significant difference found was between Lancer elastics with and without latex in dry conditions, force loss being greater for latex-free elastics. Comparing brands, there was greater force loss with GAC than with Lancer. Comparing elastic force at the eight-hour mark and the twenty-four hour mark to the initial force (only in wet conditions), GAC latex and non-latex and Lancer latex elastics showed significantly less force at eight and twenty four hours than initially. On the other hand, Lancer non-latex was the only type of elastics that did not show a significant decrease in its initial elastic characteristics at eight hours in wet conditions. Nevertheless, Lancer non-latex did show significantly less force in wet conditions at twenty four-hours than the forces observed initially and at eight-hours.

Introduction

Latex has widespread uses within dentistry as in many other fields of medicine. Natural latex is an isoprene polymer of high molecular weight with small quantities of protein and fatty acids (Billmeyer, 1984). Being too weak in its natural state, it has to be processed. Latex, as such, is probably not an allergen but the addition of ammonia during processing produces proteins that are potentially allergenic. Other chemical additives used in the vulcanization process such as accelerators and anti-oxidants are themselves allergens (Cronin, 1980).

It is estimated that between 0.12 and 6 per cent of the general population and some 6.2 per cent of dental practitioners are hypersensitive to latex (ADA Council on Scientific Affairs, 1999). A latex hypersensitive individual's cutaneous exposure to latex will often produce contact dermatitis, while mucous or parenteral contact can induce anaphylactic shock (Russell *et al.*, 2001).

Since the early 90s, non-latex elastics have been made available for orthodontic use but the guidelines for the clinical use of latex-containing elastics are not necessarily applicable to non-latex elastics. For this reason, the properties of these materials need to be evaluated experimentally.

While there have been a fair number of studies of the characteristics and properties of latex-containing elastics (Yogosawa *et al.*, 1967; Andreasen and Bishara, 1970; Bishara and Andreasen, 1970; Kovatch *et al.*, 1976, Bales *et al.*, 1977; Brantley *et al.*, 1979; Young and Sandrik, 1979; Billmeyer, 1984; Chang, 1987; Holmes *et al.*, 1993; Kanchana and Godfrey, 2000; Hwang and Cha, 2003; Hanson and Lobner, 2004), studies of non-latex elastics are few and controversial (Russell *et al.*, 2001; Hwang and Cha, 2003; Kersey *et al.*, 2003a) as the various studies published to date vary with regard to the materials and methods employed, leading to varying conclusions regarding these elastics' mechanical properties. For this reason, further studies are necessary in order draw conclusions that offer a reliable clinical application.

The aim of this study was, therefore, to evaluate *in vitro*, the force of latex and non-latex elastics from two manufacturers, at 5 seconds, 8 hours, and 24 hours after having been subjected to constant stretching in both wet and dry environments. The null hypothesis of our research was that there were not significant differences in force decay among the media, compositions, brands, and times considered in this study.

Materials and methods

Latex and non-latex elastics were provided by two manufacturers: GAC (Dentsply GAC International, Inc., Bohemia, New York, USA) and Lancer Orthodontics (Lancer, Kent, Ohio, USA). All the elastics were reported to be 6.35 mm (0.25 inch) internal diameter (ID) and 4 oz (113.31 g; 1.112 N) weight.

Five hundred samples were used. Twenty-five samples of each elastic type were used for each test. The elastics came in sealed packaging and were stored in a cool dark place until the moment of use when they were stretched to three times their ID on a stainless steel plate, 140 mm in diameter and 9 mm thickness that had 25 pairs of pins separated by a distance of 19.05 mm. The pins had a narrowed portion of 1.4 mm in height and 1.5 mm of diameter facilitating the placement of the elastics and keeping them parallel to the steel base plate (Figure 1).

Two types of test were carried out: 1. dry testing in which the elastics were stretched to three times their ID at room temperature, measuring force after 5 seconds, 8 hours, and 24 hours and 2. wet testing in which the elastics were stretched to three times their ID in the same way as the dry test and submerged in distilled water at 37°C, pH = 6.7, and tested after 8 and 24 hours (Table 1).

Force evaluations were carried out using a Universal Test Machine (Autograph AGS-IKND; Shimadzu, Kyoto, Japan) with a load cell of 1 kN/100 Kgf and crosshead speed of 30 mm/minute. The elastics were stretched between two hooks, one on the fixed base and the other on the machine head, both with a calibre of 1.5 mm and ID measuring 8 mm. The machine head was stopped when the elastic was stretched to three times its ID (19.05 mm). Its peak force was measured in Newtons.

Initial force detected in the test (measured at 5 seconds) was compared to that specified by the manufacturer by means of the *t*-test for two independent samples ($P < 0.05$). Differences between brands, composition, and wet/dry conditions were analysed with a three-way analysis of variance (ANOVA) ($P < 0.05$) and a minimum significant difference test (MSD; $P < 0.05$). A one-factor ANOVA and an MSD test were used to establish the presence of significant differences between initial forces and forces after 8 and 24 hours in wet conditions.

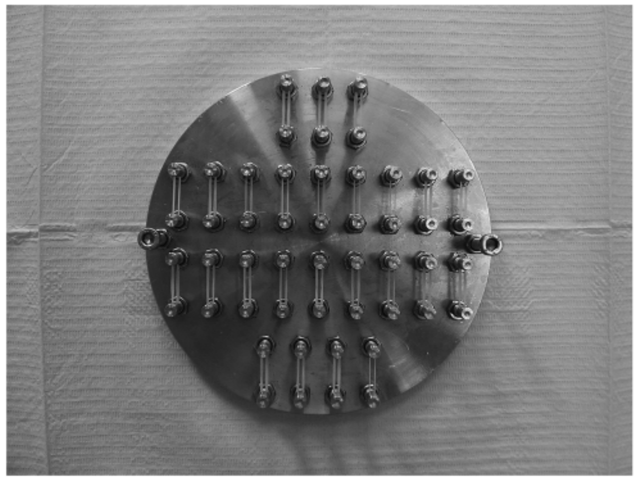

Figure 1 Elastics stretched on stainless steel plate.

Table 1 Tests carried out, mean, standard deviation (SD), range, percentage of initial force (%IF), and the manufacturer value (MV) in Newtons, generated by each test group of elastics stretched to three times their internal diameter.

		Elastic	Mean	SD	Range	% IF	MV
GAC	Latex	GACLD5S	1.33	0.07	0.23	0.00	
		GACLD8H	1.35	0.10	0.42	−1.23	1.11
		GACLD24H	1.30	0.09	0.30	2.63	
		GACLW8H	1.13	0.09	0.40	15.46	
		GACLW24H	1.14	0.07	0.27	14.60	
	Non-latex	GACNLD5S	1.39	0.10	0.37	0.00	
		GACNLD8H	1.36	0.08	0.28	2.38	1.11
		GACNLD24H	1.28	0.09	0.30	8.09	
		GACNLW8H	1.10	0.10	0.33	21.21	
		GACNLW24H	1.12	0.06	0.25	19.92	
Lancer	Latex	LANCERLD5S	1.47	0.26	0.97	0.00	
		LANCERLD8H	1.51	0.23	0.90	−2.81	1.11
		LANCERLD24H	1.49	0.20	0.81	−1.60	
		LANCERLW8H	1.29	0.18	0.70	12.13	
		LANCERLW24H	1.25	0.14	0.55	14.86	
	Non-latex	LANCERNLD5S	1.33	0.13	0.43	0.00	
		LANCERNLD8H	1.36	0.03	0.13	−1.85	1.11
		LANCERNLD24H	1.28	0.03	0.12	3.87	
		LANCERNLW8H	1.36	0.04	0.17	−1.74	
		LANCERNLW24H	1.19	0.02	0.10	10.31	

L, latex; NL, non-latex; D, dry test; W, wet test; 5S, 5 seconds; 8H, 8 hours; 24H, 24 hours.

Results

Means, standard deviations, and ranges of force values generated by each group of elastics when stretched to three times their ID and percentages of initial force lost are shown in Table 1.

We obtained the following initial forces: GAC with latex 1.33 N, GAC non-latex 1.39 N, Lancer with latex 1.46 N, and Lancer non-latex 1.33 N. For all the elastics, initial force was found to be significantly greater than the value specified by the manufacturer (1.11 N; $P < 0.05$).

Table 2 shows the results of the three-way ANOVA. We found significance in five double interactions and in two triple interactions ($P < 0.05$).

Data analysis showed significant differences between wet and dry environments, composition, brands, and time spans ($P < 0.05$; Table 3).

Table 2 Three-way analysis of variance; dependent variable: strength (Newtons).

	Significance
Corrected model	0.00
Intersection	0.00
Brand	0.00
Composition	0.00
Media	0.00
Time	0.00
Brand–composition	0.00*
Brand–media	0.00*
Composition–media	0.00*
Brand–composition–media	0.00*
Brand–time	0.03*
Composition–time	0.02*
Brand–composition–time	0.27
Media–time	0.58
Brand–media–time	0.00*
Composition–media–time	0.78
Brand–composition–media–time	0.32

We found significance in five double interactions and in two triple interactions.*$P < 0.05$.

Table 3 contrasts the different times at which measurements were taken against the elastic characteristics revealed. The table is divided into three parts horizontally. The first shows the differences between wet/dry conditions, the second the differences between elastic composition (with latex and non-latex), and the third the differences between brands (GAC and Lancer).

In order to explain the results shown in Table 3, when we speak of consistent trends, this refers to the same relation at all the times when force was measured (5 seconds, 8 hours, and 24 hours). When we speak of inconsistent trends, this means that a constant relation was not found across the times of measurement.

In the first part of the Table 3, four consistent trends can be seen: force values of GAC latex-containing elastics under dry conditions were significantly greater than force values found for latex GAC in wet conditions ($P < 0.05$). Force values found for non-latex GAC in dry were significantly greater than those for non-latex GAC in wet ($P < 0.05$). Lancer latex in dry showed force values significantly greater than Lancer latex in wet ($P < 0.05$). No significant differences were found between forces for non-latex Lancer elastics when wet or dry environments were compared ($P > 0.05$).

In the second part of the Table 4, consistent trends can be seen: in dry conditions, no significant differences were detected between GAC elastics whether with latex or non-latex ($P > 0.05$). In wet conditions, no significant differences were detected between GAC elastics whether latex or non-latex ($P > 0.05$). With Lancer elastics in dry conditions, elastics with latex showed significantly greater force than non-latex elastics ($P < 0.05$). No significant differences were found between force values for Lancer elastics whether latex or non-latex in wet conditions ($P > 0.05$).

In the third part of the Table 2, consistent trends can be seen: force found for Lancer elastics with latex in dry was significantly greater than their GAC equivalent ($P < 0.05$).

Table 3 Significant differences in force maintained between brand, composition, and wet/dry medium.

	5 s force	8 h force	24 h force
GAC latex	------------------------	**DRY > WET**	**DRY > WET**
GAC non-latex	------------------------	**DRY > WET**	**DRY > WET**
Lancer latex	------------------------	**DRY > WET**	**DRY > WET**
Lancer non-latex	------------------------	**NS**	**NS**
GAC dry	**NS**	**NS**	**NS**
GAC wet	------------------------	**NS**	**NS**
Lancer dry	**LATEX > NON-LATEX**	**LATEX > NON-LATEX**	**LATEX > NON-LATEX**
Lancer wet	------------------------	**NS**	**NS**
Latex dry	**LANCER > GAC**	**LANCER > GAC**	**LANCER > GAC**
Latex wet	------------------------	LANCER > GAC	NS
Non-latex dry	**NS**	**NS**	**NS**
Non-latex wet	------------------------	LANCER > GAC	NS

NS: No significant difference; ---------------: no measurement taken; bold-type letter: consistent tendencies; normal-type letter: inconsistent tendencies; $P < 0.05$

Table 4 GAC and Lancer significant differences across test times (in Newtons).

	Initial force in dry	At 8 h in wet	At 24 h in wet
GAC latex	1.33 (0.07)a	1.13 (0.08)b	1.13 (0.07)b
GAC non-latex	1.39 (0.10)a	1.09 (0.10)b	1.11 (0.06)b
Lancer latex	1.46 (0.26)a	1.28 (0.18)b	1.24 (0.15)b
Lancer non-latex	1.33 (0.13)a	1.35 (0.04)a	1.19 (0.02)b

Different letters horizontally indicate significant differences. $P < 0.05$.

No significant differences were found between non-latex GAC elastics in dry and their Lancer equivalent ($P > 0.05$). We can also see two inconsistent trends: force values found with Lancer latex and non-latex elastics in wet conditions were significantly greater than values generated by their GAC equivalents at the 8 hour mark ($P < 0.05$), while at 24 hours, no significant differences were found ($P > 0.05$).

In the Table 4, we can see that remaining forces after 8 and 24 hours, in the wet environment, for both latex and non-latex GAC and latex Lancer elastics, were significantly lower than initial forces. However, non-latex Lancer elastic was the only type of elastic that did not show a significant decreas in its initial elastic characteristics at 8 hours in wet conditions; nevertheless, it showed significantly less force at 24 hours than initially and at 8 hours evaluation ($P < 0.05$).

Discussion

As in tests carried out by Hwang and Cha (2003), the present study evaluated initial force after stretching elastics for 5 seconds, giving the bands time to stabilize before the recordings were made. Various authors (Kovatch *et al.*, 1976; Brantley *et al.*, 1979) have noted that after the first 5 seconds of stretching, force decreases over time in an exponential way.

In our study, most types and sizes of elastics showed a decrease in force over time when compared with their initial force. In Table 1, we observe that in five cases, the elastics' mean force slightly increased over time. Different authors (Bishara and Andreasen, 1970; Brantley *et al.*, 1979) also observed similar performances. Bishara and Andreasen (1970) comment literally that 'on rare occasions the mean force of elastics slightly increased in the subsequent period of time', and they attributed it to measurement error rather than any significant phenomenon of the material itself. In any case, the force increase values registered were in hundredths of Newtons and so practically irrelevant in clinical application.

Orthodontic elastics are classified according to a standard ´force index`, which is the tension force indicated by the manufacturer when the elastic is stretched to three times its ID. Our results coincide with the findings of other studies which also found that for both latex (Kanchana and Godfrey, 2000; Russell *et al.*, 2001; Hwang and Cha, 2003) and non-latex (Russell *et al.*, 2001; Kersey *et al.*, 2003b) elastics, initial forces were greater than those specified by their manufacturers. Furthermore, in our study, none of the materials ever fell below the manufacturers' data throughout the test. Nevertheless, there are several other studies in which it was found that latex (Kersey *et al.*, 2003a) and non-latex (Hwang and Cha, 2003; Kersey *et al.*, 2003a) elastics showed initial forces that were lower than the manufacturer's indications.

Our results show that the GAC latex elastics in dry conditions kept their initial force at the 8 hours interval and lost almost 3 per cent at the 24 hours interval, while in wet conditions, 15 per cent of initial force was already lost at the 8 hours interval. Lancer latex elastics in dry kept their initial force all the way until the 24 hours interval, while in wet conditions, they lost 12 per cent of their initial force at the 8 hours interval and 15 per cent at the 24 hours interval. All elastomeric materials, including those manufactured using natural latex, suffer fatigue (Billmeyer, 1984). Bell (1951) noted that the action of mouth fluids can reduce their effectiveness by as much as 20 per cent after 24 hours of constant use. This author, in a series of tests that were made upon samples that had been stretched constantly for periods of 12 and 24 hours in the dry state, found that prolonged pressure caused 1 per cent or less decrease in applied force. In another study of latex-containing elastics of TP, Rocky Mountain Orthodontics and Dentaurum (Hwang and Cha, 2003), it was found that force loss after 24 hours in dry was between 13 and 16 per cent and between 23 and 29 per cent in wet.

GAC non-latex elastics in the dry environment lost 2 per cent of initial force at the 8 hours interval and 8 per cent at the 24 hours interval, while in wet, they lost already around 20 per cent at the 8 hours interval. Lancer non-latex elastics in dry conditions kept their initial force at the 8 hours interval but lost about 4 per cent at the 24 hours interval. In the wet medium, they kept their initial force at the 8 hours interval but lost 10 per cent at the 24 hours interval. In one study of non-latex elastics of JEPE (Hwang and Cha, 2003), it was found that force lost at 24 hours in a dry medium was 24 per cent of initial force and 73 per cent in a wet medium.

Our data showed that when significant differences between wet and dry environments were found, the greater force loss occurred in wet conditions. There are a number of studies that failed to detect significant differences in force loss between wet and dry media (Thomas *et al.*, 1966; Andreasen and Bishara, 1970; Bales *et al.*, 1977). Nevertheless, several other studies do (Hwang and Cha, 2003; Wong, 1976). Lancer non-latex elastics performed better in our study than GAC non-latex and because of that we could not find significant differences between wet and dry environment at the 8 and 24 hours intervals. Perhaps, the manufacture process is better in Lancer than in GAC in this kind of elastics and/or the chemical or structural characteristics of the raw materials are the reasons for these findings.

When force was compared between latex and non-latex elastics, for GAC, whether in wet or dry media, significant differences were not found between initial forces, forces after 8 or 24 hours nor were significant differences found for Lancer in the wet medium. However, Lancer elastics in dry conditions did show significant differences by which elastics containing latex produced significantly greater force than non-latex elastics initially, at 8 hours, and at 24 hours.

When the two brands were compared, our results showed that Lancer elastics containing latex in dry conditions maintained force levels that were significantly greater than GAC, both initially, at 8 hours, and at 24 hours, while in wet conditions, Lancer elastics both with and without latex produced force levels significantly greater than GAC at 8 hours but not at 24 hours. One study (Kersey *et al.*, 2003b) found that GAC non-latex elastics in a wet medium had maintained significantly greater force after 24 hours than all other brands tested (American Orthodontics, Ortho Organizers and Masel). Nevertheless, another study (Russell *et al.*, 2001) found that regarding the force loss from 1 hour to 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 the 1 hour mark, when the medium and heavy elastics produced the same force levels. No comparisons can be made between Lancer and a wider range of brands as, as far as we are aware, no studies have been carried out.

When force levels maintained at 8 and 24 hours were compared in relation to initial force, in wet conditions, it was found that latex or non-latex GAC elastics and also latex Lancer generated forces at 8 and 24 hours that were significantly less than initially, while Lancer non-latex elastics produced a force that was significantly less at 24 hours than initially and at 8 hours. For this reason, in base of our results, Lancer non-latex elastics are the best option among the elastics evaluated in this study if they are not going to be worn more than 8 hours because the other types of elastics evaluated did not even maintain their initial characteristics at this time point (8 hours), but we should remember that the results were obtained under laboratory conditions. Timing for changing elastics is a clinical issue, but some authors (Kersey *et al.*, 2003a,b) stand for changing elastics every 8 hours. In real practice, elastics are exposed to numerous intraoral factors. The mechanical properties of elastomers are influenced by the rate and duration of loading as well as environmental conditions (Eliades *et al.*, 2004). For example, it has been reported that oral pH has a significant influence on the decay rate of elastics. pH levels above neutral are more hostile, increasing the force–decay rates of elastics (Ferriter and Meyers, 1990). Clinical decisions cannot be taken on the basis of an *in vitro* experiment but is our opinion that this kind of research is useful to guide clinical experiments in the future.

As Kersey *et al.* (2003a), we think that 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 produced fall within the expected range, as specified by the manufacturer. Clinically, the decision has to be made about whether to start with a higher force than deemed necessary or end up with a lower force than desired after only a short time in the mouth. Further study is needed using different brands of latex and non-latex elastics along with different sizes and force levels.

As Young and Sandrik (1979), we have observed many studies about elastomers in dental use and their force loss over time with very varied outcomes. The controversy resulting from the varying methods, materials, and brands used in these tests make it difficult to compare the various products involved. In our opinion, a standardized protocol is needed for this type of testing in order to make reliable comparisons between studies.

Conclusions

1. Whenever significant differences were found between wet and dry media, the loss of force was greater in wet than in dry.
2. Whenever significant differences were found between compositions (latex or non-latex), the force loss was greater for non-latex elastics than elastics containing latex.
3. Whenever significant differences were found between brands, the force loss was greater for GAC elastics than for Lancer elastics.
4. In wet conditions GAC elastics both with and without latex and Lancer elastics with latex generated forces at 8 and at 24 hours that were significantly less than initially. On the other hand, Lancer non-latex was the only type of elastics that did not show a significant decrease in its initial elastic characteristics at 8 hours in wet conditions. Nevertheless, Lancer non-latex did show significantly less force in wet conditions at 24 hours than initially and at 8 hours. For this reason Lancer non-latex elastics are the best option among the elastics evaluated in this study if they are not going to be worn more than 8 hours, because the other types of elastics evaluated did not even maintain their initial characteristics at this time point (eight hours). Notwithstanding, an *in vivo* study would be necessary in order to confirm these results.

References

ADA Council on Scientific Affairs 1999 The dental team and latex hypersensitivity. Journal of the American Dental Association 130: 257–264

Andreasen G F, Bishara S E 1970 Comparison of Alastik chains to elastics involved with intra-arch molar to molar forces. Angle Orthodontist 40: 151–158

Bales T R, Chaconas S J, Caputo A A 1977 Force-extension characteristics of orthodontic elastics. American Journal of Orthodontics 72: 296–302

Bell W R 1951 A study of applied force as related to the use of elastics and coil Springs. Angle Orthodontist 21: 151–154

Billmeyer F W 1984 Textbook of polymer science. Wiley & Sons, New York, pp. 361–382.

Bishara S E, Andreasen G F 1970 A comparison of time related forces between plastic Alastiks and latex elastics. Angle Orthodontics 40: 319–328

Brantley W A, Salander S, Myers C L, Winders R V 1979 Effects of pre-stretching on force degradation characteristics of plastic modules. Angle Orthodontics 49: 37–43

Chang H F 1987 Effects of instantaneous pre-stretching on force degradation characteristics of orthodontic plastic modules. Proceeding of the National Science Council, Republic of China [B] 11: 45–53

Cronin E 1980 Contact dermatitis. Edinburgh, UK: Churchill Livingstone

Eliades T, Eliades G, Silikas N, Watts D C 2004 Tensile properties of orthodontic elastomeric chains. European Journal of Orthodontics 26: 157–162

Ferriter J P, Meyers C E 1990 The effect of hydrogen ion concentration on the force-degradation rate of orthodontic polyurethane chain elastics. American Journal of Orthodontics and Dentofacial Orthopedics 98: 404–410

Hanson M, Lobner D 2004 In vitro neuronal cytotoxicity of latex and nonlatex orthodontic elastics. American Journal of Orthodontics and Dentofacial Orthopedics 126: 65–70

Holmes J, Barker M K, Walley E K, Tuncay O C 1993 Cytotoxicity of orthodontic elastics. American Journal of Orthodontics and Dentofacial Orthopedics 104: 188–191

Hwang C J, Cha J Y 2003 Mechanical and biological comparison of latex and silicone rubber bands. American Journal of Orthodontics and Dentofacial Orthopedics 124: 379–386

Kanchana P, Godfrey K 2000 Calibration of force extension and force degradation characteristics of orthodontic latex elastics. American Journal of Orthodontics and Dentofacial Orthopedics 118: 280–287

Kersey M L, Glover K E, Heo G, Rabound D, Major P W 2003a A comparison of dynamic and static testing of latex and non-latex orthodontic elastics. Angle Orthodontist 73: 181–186

Kersey M L, Glover K, Heo G, Rabound D, Major P W 2003b An in vitro comparison of 4 brands of non-latex orthodontic elastics. American Journal of Orthodontics and Dentofacial Orthopedics 123: 401–407

Kovatch J S, Lautenschlager E P, Apfel D A, Keller J C 1976 Load-extension-time behavior of orthodontic Alastiks. Journal of Dental Research 55: 783–786

Russell K A, Milne A D, Khanna R A, Lee J M 2001 In vitro assessment of the mechanical properties of latex and non-latex orthodontic elastics. American Journal of Orthodontics and Dentofacial Orhopedics 120: 36–44

Thomas R B, Sapiro J C, Angle B C 1966 Force extension characteristics of orthodontic elastics. American Journal of Orthodontics 72: 296–302

Wong A K 1976 Orthodontic elastic materials. Angle Orthodontist 46: 196–205

Yogosawa F, Nisimaki H, Ono E 1967 Degradation of orthodontic elastics. Journal of the Japanese Orthodontic Society 26: 49–55

Young J, Sandrik J L 1979 The influence of preloading on stress relaxation of orthodontic elastic polymers. Angle Orthodontist 49: 104–109