In vitro evaluation of force delivered by elastomeric chains

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Abstract

Objective: To evaluate and compare, *in vitro*, the decrease in the forces delivered in three groups of elastomeric chains, produced by the same manufacturer, according to the distance between links (short, medium, long). **Methods:** The segments of elastomeric chains were stretched and kept activated during the trial using a device developed especially for this purpose, which also allowed force readings. Force degradation was evaluated by measuring force along time and calculating the percentage of force decrease from initial force at each time interval and for each specimen under test. **Results and Conclusions:** Data were statistically analyzed and results showed that at the different time points after initial readings, force intensity varied within and between groups. Readings of remaining forces at each time moment compared with the initial reference force revealed statistically significant differences in all the comparisons in each group of elastics (short, medium, long). Although the comparisons between forces delivered at each time point revealed statistically significant differences, these differences do not seem to have a clinical significance. The space between links does not seem to be a clinically significant characteristic in force degradation along time.

Keywords: Orthodontic appliances. Dental materials. Elastomers.

How to cite this article: Motta AFJ, Cury-Saramago AA, Nojima LI. *In vitro evaluation of force delivered by elastomeric chains*. Dental Press J Orthod. 2011 Nov-Dec;16(6):36.e1-8.

» The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.

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INTRODUCTION

Orthodontics is based on the principle that an external force intentionally applied to a tooth can promote tooth movement and produce a biological response from dentoalveolar tissues. No consensus has been reached about what is the ideal orthodontic force to achieve tooth movement, but continuous low forces have been described as optimal.[4] The knowledge of orthodontic biomechanics provides resources to use a number of force systems capable of promoting optimal force at the highest movement speed without causing discomfort to the patient or damage to supporting tissues.

Elastomeric chains were first used in orthodontics in the 1960s,[3-8] and their applications have increased along time due to the many advantages that they have over other ways to replace metal ligatures, closure archwires, and open and closed coil springs. They promote space closure, rotation corrections and movement canines distally.[19] Elastomeric chains are also economic, comfortable and easily placed and removed, which reduces working time and does not require patient cooperation.[23] They are also relatively hygienic and often compatible with the oral mucosa, factors that contribute to their high level of acceptance among orthodontists.[4,7,12,24] However, they are not capable of retaining a continuous force strong enough to move teeth.[3]

The mechanical properties of elastomeric chains change along time due to the amount of stretching to which they are submitted and because of factors such as water and saliva absorption, permanent deformation, sensitivity to saliva pH and temperature variations in the oral environment.[8] The distance between links of elastomeric chains — often described as short, medium or long — as well as their configurations also seem to affect their behavior.[8,9,10,28] According to some authors, short elastomeric chain modules, which have no distance between the links, retain the greatest percentage of force along time.[3,8]

Elastomeric chains are usually placed and replaced at three- to four-week intervals.[6] After that time, they seem to be permanently elongated and discolored.[1] Also, they should not be used continuously for more than six weeks, due to both their incapacity to retain their mechanical properties and the possible bacterial biofilm formation on the surface of the material.[12]

According to some authors, the greatest decrease in force delivered by elastomeric chains occurs in the first hour,[15,16,18] but losses of 33% to 50%[11] have been found in the first 24 hours after placement. Other authors found losses of up to 73% in the same time interval followed by three weeks during which forces delivered were considerably constant.[1,27]

To conduct orthodontic treatments satisfactorily, it is necessary to know the characteristics and properties of orthodontic elastics, as well as to monitor the amount of force delivered at different time intervals. Several studies investigated the mechanical properties of elastomeric chains, but findings reported in the literature are contradictory, particularly in terms of decrease of force delivered along time.[4,10,13-18]

This study evaluated and compared, in vitro, the initial force delivered and its decrease measured at pre-established time intervals in elastomeric chains from the same manufacturer divided into three groups according to the distance between links: Short, medium, long.

MATERIAL AND METHODS

Elastomeric chains produced by Dental Morelli (Sorocaba, Brazil) and classified according to the distance between links (short - 60.05.501; medium - 60.05.511; long - 60.05.521) were included in this study. Before tests, the elastomeric chains were kept in their original packaging, according to manufacturer's instructions.

Each group had 20 elastomeric chain segments, and groups were formed according to distance between links: Short group, medium group, and long group. The elastomeric chains were carefully re-

moved from their spools, and care was taken not to stretch them. For all the elastomeric chain segments, only the central links were activated, and one extra link was left at each end to rule out the chance of accidental damage to the chain during cutting and spool removal, which might have rendered the structure fragile and prone to fractures, although such damage might not be visually detected.

A device with two platforms, one fixed and one movable, and hooks in the ends was manufactured especially to keep the elastomeric chains activated during the experiment and to allow readings of the delivered forces. The device platforms were adjusted to a distance of 20 mm between the hooks using a digital caliper (serial number 001296; Starret Indústria e Comércio Ltda., Itu, São Paulo, Brazil) which simulated the distance between the mesial tie-wing of the canine bracket and the distal tie-wing of the second premolar.[8,17] After that, the elastomeric chain segments were placed in the device and stretched to deliver an initial force of about 200 gf.

Measurements were made at the following time intervals: Baseline, 1 hour, 24 hours, and 1, 2, 3 and 4 weeks after the chain activation.

Force degradation was evaluated by measuring forces along time and calculating the percentage of differences from initial force at each time interval and for each specimen under test.

The devices with the activated elastomeric chain segments were immersed in artificial saliva and kept in an incubator at a controlled temperature of 37±1 °C. A few moments before measurements, the devices were removed from the container and, after the tests, were returned to it.

The level of artificial saliva in the container was measured everyday to ensure that the chains remained immersed in this solution at all times. The artificial saliva was prepared at the Pharmacy of the Federal University of Rio de Janeiro (Brazil).

The distance between the hooks of the fixed and movable platforms was shortened 0.5 mm each week to simulate orthodontic distal movement of a canine.[5,11] Therefore, the distance between the platforms at the end of the first week was 19.5 mm, and successively so until it reached 18 mm at the end of the experiment.

Statistical analysis

Data were analyzed statistically by comparing the values of force delivered by the elastomeric chains to check the existence of statistically significant differences between groups for each time interval separately and within each group, considering the force differences from one time point to the other.

The Shapiro-Wilk tests were used to check the normal distribution of data. To check differences between the three groups, parametric analysis of variance (ANOVA) was used. The Levene test was used for normally distributed data, and the non-parametric Kruskal-Wallis test for groups with non-normally distributed data, followed by the Mann-Whitney test to detect differences. The level of significance was set at 5% for all the descriptive tests listed above.

The non-parametric Friedman and Wilcoxon tests were used to check differences within each group. The level of significance was set at 1%.

RESULTS

Means and standard deviations of the force delivered by the elastomeric chains in the short, medium and long groups, as well as the mean percentage of force degradation at the different time points are shown in Table 1.

Table 2 shows the levels of significance for the mean forces delivered (gf) in the comparison between groups at the different time points.

Mean forces initially delivered in the short, medium and long groups were 237.3 gf, 227.3 gf and 230.3 gf, respectively. There was a statistically significant difference ($p<0.05$) between the values of force delivered by short elastomeric chains and the other two groups (medium and long), but there were no statistically significant differences ($p>0.05$) between the forces in these two latter groups.

TABLE 1 - Means and standard deviations of the force (in gram-force) delivered by the elastomeric chains in the short, medium and long groups and the mean percentage of force degradation at the different time points.

Time point	Group	Force delivered		Force degradation	
		mean (gf)	s.d.	mean (%)	s.d.
Initial force	short	237.25	11.64	-	-
	medium	227.25	11.29	-	-
	long	230.25	7.52	-	-
1 hour	short	230.00	12.25	3.06	1.73
	medium	218.25	10.04	3.92	2.13
	long	219.25	7.99	4.78	1.66
24 hours	short	193.25	11.50	18.55	2.48
	medium	182.25	6.97	19.69	3.44
	long	185.75	6.34	19.32	1.61
1 week	short	148.75	10.24	37.29	3.23
	medium	148.25	7.66	34.68	3.65
	long	149.50	8.41	35.08	2.75
2 weeks	short	136.25	11.11	42.61	2.86
	medium	130.75	7.66	42.44	2.46
	long	134.00	6.81	41.79	2.54
3 weeks	short	112.25	10.82	52.74	3.08
	medium	116.25	7.59	48.85	2.10
	long	120.00	6.69	47.89	2.28
4 weeks	short	102.75	8.19	56.72	2.21
	medium	96.25	6.86	57.63	2.41
	long	109.75	5.95	52.35	1.71

TABLE 2 - Levels of significance for the different mean force (gf) delivered in the comparison between groups at the different time points.

Time point	Groups		
	short X medium	short X long	medium X long
Initial force	10*	7*	-3^{ns}
1 hour	11.75*	10.75*	-1^{ns}
24 hours	11*	7.5*	-3.5^{ns}
1 week	0.5^{ns}	-0.75^{ns}	-1.25^{ns}
2 weeks	5.5^{ns}	2.25^{ns}	-3.25^{ns}
3 weeks	-4*	-7.75*	-3.75*
4 weeks	-7*	6*	-13.5*

* = statistically significant (p>0.05), ns = non-significant.

For the comparisons between the initial forces and the remaining forces at each time point within each group of elastomeric chains (short, medium, long), the non-parametric Friedman and Wilcoxon tests were used, and the results revealed statistically significant differences ($p<0.01$) in all the comparisons made.

The results of the elastomeric chain groups at the first time points (initial, 1 hour, 24 hours) were compared using ANOVA because these data were normally distributed, and followed by multiple comparison methods to detect differences. In the following time points (1, 2, 3, 4 weeks), data were non-normally distributed, and the comparisons of the elastomeric chain groups were preceded by non-parametric methods, specifically the Kruskal-Wallis analysis of variance, and followed by the Mann-Whitney test to detect differences.

One hour after activation, the values for the short, medium and long groups were 230 gf, 218.25 gf and 219.25 gf, respectively. After one hour and at a statistically significant level ($p<0.05$), the force delivered by short elastomeric chains was greater than that delivered by either of the other two groups (medium and long), and there were no statistically significant difference ($p>0.05$) between the force values in these two latter groups.

The remaining force values obtained in readings after 24 hours for the short, medium and long elastomeric chains were 193.25 gf, 182.25 gf and 185.75 gf, respectively. Also, statistical analyses revealed a significant difference between forces in the Short group when compared with the Medium and Long groups.

One week after the beginning of measurements, mean forces delivered by the short, medium and long elastomeric chains were 148.75 gf, 148.25 gf and 149.50 gf, respectively. At a level of significance of 0.05, the non-parametric analysis of variance (Kruskal-Wallis test) found evidence of homogeneity ($p>0.05$) between the remaining forces in the three groups of elastomeric chains. There were no statistically significant differences in remaining forces between the elastomeric chain groups one week after activation.

After two weeks, mean values were 136.25 gf, 130.75 gf and 134 gf in the Short, Medium and Long groups. At a level of significance of 0.05, the non-parametric analysis of variance (Kruskal-Wallis test) found evidence of homogeneity ($p>0.05$) between the remaining forces in the three groups of elastomeric chains. There were no statistically significant differences in remaining forces between the elastomeric chain groups at two weeks after activation.

At three weeks, the force delivered by the short elastomeric chains, 112.25 gf, was statistically lower ($p<0.05$) than that in the Medium and Long groups (116.25 and 120 gf). However, there were no statistically significant differences ($p>0.05$) between the remaining forces delivered by these two latter groups.

The statistical analysis of the values at four weeks revealed that the remaining forces delivered by the elastomeric chains were all different from each other; in the Long group, the remaining force (109.75 gf) was statistically greater ($p<0.05$) than in the Short group (102.75 gf), which, in turn, was statistically greater ($p<0.05$) than in the Medium group (96.25 gf).

DISCUSSION

The vast literature on the properties of elastomeric chains is difficult to analyze and compare due to the variable nature of study methods, the differences between the configuration of several chains already tested, and the impossibility to find out the exact composition of these materials, often kept secret by manufacturers.

In addition to the influences of environmental changes or compositions and the effects of disinfection on elastomeric chains, the forces delivered and their degradation, as well as their pre-stretching, are variables that have been analyzed.[20] However, it seems impossible to control all the factors that may affect a clinical situation.[23]

According to some studies,[2,13,14,15] the degradation of forces delivered by synthetic elastic materials, when evaluated in a wet environment, is significantly greater than when in a dry environment. Therefore, the elastomeric chain segments in this study were immersed in artificial saliva. The temperature was kept at 37±1 °C because this is the temperature of the human body and it is known that temperature significantly affects the degradation of the force delivered by elastomeric chains.[14,25] Elastomeric chain pre-streching does not seem to induce any significant improvement in the mechanical properties of elastic materials; therefore, this procedure was not used in this study.[6,16]

The purpose of this study was not to compare elastomeric chains from different manufacturers, but, rather, to evaluate the behavior of chains with different distances between links (short, medium, long) produced by the same manufacturer. Therefore, the synthetic elastic material used in this study was chosen for its wide application and acceptance by orthodontists, and our purpose was to provide additional knowledge about their mechanical behavior.

Some authors evaluated the behavior of elastic materials during three weeks,[4,8,27] while others used four weeks or longer times.[11,16,17,23] We chose a time interval of four weeks because it is the usual interval between orthodontic visits.

The initial intensity of the force delivered by the elastics was standardized. However, its variation could not be avoided and was found even within the same group, probably due to the random spatial configurations of the polymer macromolecules, previously reported.[9] Similar variations were also reported by other authors.[1,11] The initial value adopted, about 200 gf, is within the range classified as adequate for distal orthodontic movement of canines in cases of extraction of the first premolar.[21,22,26]

In the subsequent time points, force intensity varied considerably within each group at the different time points. Both the elastomeric chains in the short group and those in the medium and long groups had, from the first hour on, statistically

significant differences from the force delivered initially. The percentages or remaining force in comparison with initial values for each group of elastomeric chains under study at each time point are shown in Figure 1.

The force used for distal canine movement along time degrades due to two factors: The relative movement of teeth used for anchorage, and the degradation of the elastomeric chains themselves.[12] Therefore, the decrease in the distance between the device hooks seems to be justified as it aimed at simulating the effect of tooth movement over the decrease of elastomeric chain force.

Elastomeric chains lose a large amount of the force initially delivered during the first day after activation and may, according to some authors, have a decrease of up to 75% of the initial force.[13,18] Andreasen and Bishara[1] recommend the use of an initial force 40% greater than optimal force for a certain orthodontic movement to compensate for the degradation that usually occurs in the first 24 hours. However, other authors suggest that there are no differences in the final outcome of expected tooth movement when greater forces are applied.[5] Moreover, increased forces might cause more patient discomfort and other complications, such as distant bone resorption.[28] In this study, about 20% of the initial force was lost in the same time interval, which suggests that there are differences between products from different manufacturers, as well as in variables used in each study method.

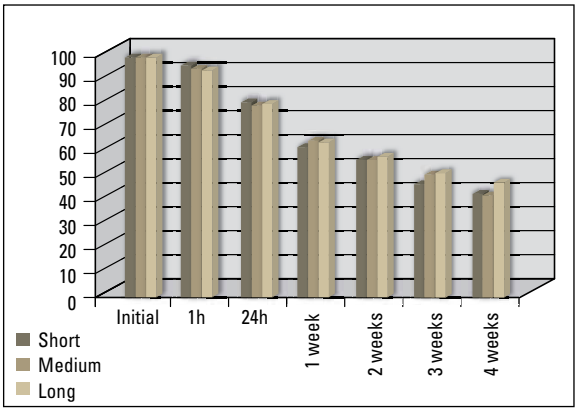

FIGURE 1 - Graphic representation of remaining force percentage, for each studied group of elastomeric chain, for each experimental time in relation to the initial values.

The analysis of force degradation along time revealed that the three groups of elastomeric chains had a substantial reduction in force delivered, and reached a mean percentage of about 55% decrease from initial force at the end of the trial (Fig 1). From the third week on, remaining forces seemed not to be within the optimal range for orthodontic tooth movement any longer.[22,26] However, according to the results reported by Boester and Johnston,[5] it is still possible to move canines distally using this force, although more slowly.

The elastomeric chains in the short group had a mean initial force greater than that in the other groups, but at the end of the trial the greatest value was found in the long group. Our results differ from those reported by other authors[4-8], who found that short elastomeric chain modules with no spaces between the links retain the greatest percentage of force along time.

Mean percentage values found in this study for force degradation at the different time intervals under study differed from those found in other studies, which might be assigned to the fact that elastomeric material was produced by different manufacturers and had different compositions. Moreover, there are method differences between studies, as well as limitations due to details of configurations already tested, such as color and distances between links of the elastomeric chains.

Although the comparisons between forces delivered at each time point revealed statistically significant differences between the Short, Medium and Long groups, these differences do not seem to have any clinical significance because the greatest difference was about 12 gf between the Short and Medium group, which is not enough, clinically, to affect the resulting tooth movement.

CONCLUSIONS

After the analysis of comparisons between groups of elastomeric chains with short, medium and long distances between links, we concluded that this difference does not seem to be a clinically significant characteristic of force degradation along time. In the three groups of elastomeric chains, there was a considerable decrease of the force delivered, and the mean percentage of decrease from initial values to the end of the trial was about 55%. The interval between visits to replace the segments of grey elastomeric chains in any of the three configurations of the brand studied here should be three to four weeks. This is supported by findings in the literature and the results of this study and tested for tooth movements in cases of space closure after extraction of the first premolar and the distal movement of the canine.

REFERENCES

1. Andreasen GF, Bishara S. Comparison of alastik chains of elastics involved with intra-arch molar-to-molar forces. Am J Orthod. 1971;60(2):200-1.
2. Ash JL, Nikolai RJ. Relaxation of orthodontic elastomeric chains and modules in vitro and in vivo. J Dent Res. 1978;57(5-6):685-90.
3. Baty DL, Storie DJ, von Fraunhofer JA. Synthetic elastomeric chains: a literature review. Am J Orthod Dentofacial Orthop. 1994;105(6):536-42.
4. Baty DL, Volz JE, von Fraunhofer JA. Force delivery properties of colored elastomeric modules. Am J Orthod Dentofacial Orthop. 1994;106(1):40-6.
5. Boester CH, Johnston LE. A clinical investigation of the concepts of differential and optimal force in canine retraction. Angle Orthod. 1974;44(2):113-9.
6. Brantley WA, Salander S, Myers CL, Winders RV. Effects of prestretching on force degradation characteristics of plastic modules. Angle Orthod. 1979;49(1):37-43.
7. Chimenti C, Lecce D, Santucci L, Parziale V, Lucci M. In vitro assessment of elastomeric chain behavior. Prog Orthod. 2001;2(1):42-5.
8. De Genova DC, McInnes-Ledoux P, Weinberg R, Shaye R. Force degradation of orthodontic elastomeric chains: a product comparison study. Am J Orthod. 1985;87(5):377-84.
9. Eliades T, Eliades G, Silikas N, Watts DC. Tensile properties of orthodontic elastomeric chains. Eur J Orthod. 2004;26(2):157-62.
10. Ferreira Neto JJ, Caetano MTDO. A degradação da força de segmentos de elásticos em cadeia de diferentes tamanhos: estudo comparativo in vitro. J Bras Ortodon Ortop Facial. 2004;9(51):225-33.
11. Hershey HG, Reynolds WG. The plastic module as an orthodontic tooth-moving mechanism. Am J Orthod. 1975;67(5):554-62.
12. Howard RS, Nikolai RJ. On the relaxation of orthodontic elastic threads. Angle Orthod. 1979;49(3):167-72.
13. Huget EF, Patrick KS, Nunez LJ. Observations on the elastic behavior of a synthetic orthodontic elastomer. J Dent Res. 1990;69(2):496-501.
14. Hwang CJ, Cha JY. Mechanical and biological comparison of latex and silicone rubber bands. Am J Orthod Dentofacial Orthop. 2003;124(4):379-86.
15. Kanchana P, Godfrey K. Calibration of force extension and force degradation characteristics of orthodontic latex elastics. Am J Orthod Dentofacial Orthop. 2000;118(3):280-7.
16. Kim KH, Chung CH, Choy K, Lee JS, Vanarsdall RL. Effects of prestretching on force degradation of synthetic elastomeric chains. Am J Orthod Dentofacial Orthop. 2005;128(4):477-82.
17. Kuster R, Ingervall B, Bürgin W. Laboratory and intra-oral tests of the degradation of elastic chains. Eur J Orthod. 1986;8(3):202-8.
18. Lu TC, Wang WN, Tarng TH, Chen JW. Force decay of elastomeric chain—a serial study. Part II. Am J Orthod Dentofacial Orthop. 1993;104(4):373-7.
19. Matta ENR, Chevitarese O. Avaliação laboratorial da força liberada por elásticos plásticos. Rev Soc Bras Ortod. 1997;3(4):131-6.
20. Mayberry D, Allen R, Close J, Kinney DA. Effects of disinfection procedures on elastomeric ligatures. J Clin Orthod. 1996;30(1):49-51.
21. Quinn RS, Yoshikawa DK. A reassessment of force magnitude in orthodontics. Am J Orthod. 1985;88(3):252-60.
22. Reitan K. Some factors determining the evaluation of forces in orthodontics. Am J Orthod. 1957;43(1):32-45.
23. Rock WP, Wilson HJ, Fisher SE. Force reduction of orthodontic elastomeric chains after one month in the mouth. Br J Orthod. 1986;13(3):147-50.
24. Sonis AL, Van der Plas E, Gianelly A. A comparison of elastomeric auxiliaries versus elastic thread on premolar extraction site closure: an in vivo study. Am J Orthod. 1986;89(1):73-8.
25. Stevenson JS, Kusy RP. Force application and decay characteristics of untreated and treated polyurethane elastomeric chains. Angle Orthod. 1994;64(6):455-64; discussion 465-7.
26. Storey E, Smith R. Force in orthodontics and its relation to tooth movement. Aust J Dent. 1952;56(2):11-8.
27. Wong AK. Orthodontic elastic materials. Angle Orthod. 1976;46(2):196-205.
28. Young J, Sandrik JL. The influence of preloading on stress relaxation of orthodontic elastic polymers. Angle Orthod. 1979;49(2):104-9.

Submitted: August 22, 2008
Revised and accepted: November 26, 2008

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