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Evaluation of the effect of different stretching patterns on force decay and tensile properties of elastomeric ligatures

Amin Aminian[1], Samaneh Nakhaei[2], Raha Habib Agahi[3], Masoud Rezaeizade[4], Hamed Mirzazadeh Aliabadi[5], Majid Heidarpour[6]

[1]Department of Orthodontics, Kerman Dental School, Kerman Oral and Dental Diseases Research Center, Kerman University of Medical Science, Kerman, [2]Department of Orthodontics, Birjand Dental School, Birjand University of Medical Science, Birjand, [3]Oral and Dental Disease Research Center, Kerman University of Medical Sciences, [4]Department of Mechanical Engineering, Graduate University of Advanced Technology, [5]Department of Mechanical Engineering, Kerman University of Science, Kerman, [6]Torabinejad Dental Research Center and Department of Orthodontics, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran

ABSTRACT

Background: There have been numerous researches on elastomeric ligatures, but clinical conditions in different stages of treatment are not exactly similar to laboratory conditions. The aim of this *in vitro* study was to simulate clinical conditions and evaluate the effect of three stretching patterns on the amount of force, tensile strength (TS) and extension to TS of the elastomers during 8 weeks.

Materials and Methods: Forces, TS and extension to TS of two different brands of elastomers were measured at initial, 24 h and 2, 4, and 8-week intervals using a testing machine. During the study period, the elastomers were stored in three different types of jig (uniform stretching, 1 and 3 mm point stretching) designed by the computer-aided design and computer-aided manufacturing technique in order to simulate the different stages of orthodontic treatment.

Results: The elastomeric ligatures under study exhibited a similar force decay pattern. The maximum force decay occurred during the first 24 h (49.9% ± 15%) and the amount of force decay was 75.7% ± 8% after 8 weeks. In general, the TS decreased during the study period, and the amount of extension to TS increased.

Conclusion: Although the elastic behavior of all ligatures under study was similar, the amount of residual force, TS and extension to TS increased in elastomers under point stretching pattern.

Key Words: Elastomeric ligatures, extension to tensile strength, force decay, tensile strength

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Address for correspondence:
Dr. Samaneh Nakhaei, Department of Orthodontics, Birjand Dental School, Birjand University of Medical Science, Birjand, Iran.
E-mail: Samaneh_n85@yahoo.com

INTRODUCTION

Clinicians usually use pins, stainless steel ligatures, self-ligating clips and circular elastomers to ligate arch-wires to orthodontic brackets. In this context, elastomeric ligatures are widely used by clinicians due to their various advantages, including low cost, easy application, reduced chair time, patient comfort and satisfaction, different colors, biocompatibility, etc. Elastomeric ligatures are polyurethanes, but an exact composition has not been disclosed due to commercial issues. Polyurethane is a generic term associated with elastic polymers with a urethane linkage.[1]

The disadvantages of these materials are force decay or force relaxation due to permanent deformation of polymeric chains, water sorption, color changes

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and tooth surface decalcification due to bacterial accumulation.[2-6]

Securing arch-wires with a single elastomeric module produces forces of 50-150 g.[7] The force exerted by an elastomeric ligature depends on the initial force and force decay rate. Taloumis *et al*. reported that wall thickness and the inner diameter affect the force the ligature will produce.[1] In addition, significant force differences were reported when arch-wires were tied in different types of brackets.[8,9]

In addition to force, elastomers have two important properties: Tensile strength (TS) and extension to TS. The TS can be defined as the maximum force a material can bear before breakage and rupture. An extension to TS is measured as the extension at which maximal stress occurs.[10]

The question is whether the forces exerted by elastomeric ligatures during the leveling, alignment and finishing stages are equal or not. Under clinical conditions, unlike commonly used laboratory conditions in force decay studies, the wire is not placed uniformly within the bracket slot and is not passive. Normally, during the early stages of treatment high-stress areas that are under tension are produced by the ligature, depending on the extent of tooth malalignment and the differences in the buccolingual position of adjacent teeth. In studies carried out until date on elastomers, less attention had been paid to the exact simulation of the clinical situation and to the effect of concentrated and uniform stretching on the elastic properties of elastomers. In this study an attempt was made to evaluate the relationship between the pattern of stretching and elastic properties of elastomeric modules as close to the clinical situation as possible by designing a specific instrument using computer-aided design (CAD) and computer-aided manufacturing (CAM) technology.

The purpose of this study was to evaluate the relationship between different stretching patterns and force decay, TS and extension to TS in two commercially available gray ligatures over a period of 8 weeks.

MATERIALS AND METHODS

Gray injection molded elastomeric ligatures from Ortho Technology (Tampa, Florida, USA, Power Sticks #404-001) and Hangzhou Yamei (Sandun Town, Hangzhou, China, Ligature Ties #EL01-02) companies were studied. Ten elastomers from each company were tested in the as received condition. Thirty samples from each company were tested at 24 h and 2, 4, and 8 weeks intervals. Thirty elastomers from each company at each time interval were divided into three different stretching pattern groups, uniform stretching, 1 mm stretching, and 3 mm stretching. A total of 260 samples were evaluated in this study.

To simulate the relationship between the wire, bracket and ligatures in different stages of treatment as close to the clinical conditions as possible, three types of storage jigs were prepared for storing elastomers during the study period. The 1 and 3 mm point stretch storage jigs were designed to simulate the early stages of treatment (alignment) during which the elastomer ligates the wire to a malposed and malaligned tooth. In this stage, the wire is not completely seated within the bracket slot, giving rise to high tension stress points in the elastomer [Figure 1]. The uniform stretch jig represents the final stages of orthodontic treatment during which the teeth are aligned buccolingually, and the wire is completely seated in the bracket slot.

The storage jigs were designed and manufactured by the CAD-CAM technique, in which the designing process (CAD) was carried out with the software SOLIDWORKS 2011 (3D design, SOLIDWORKS Corp., US) and the manufacturing phase (CAM) was carried out with a CNC machine (VMC Machine, model 850, Machine Sazi Tabriz corp., Iran) and PowerMILL software (Delcam Corp., UK).

The uniform stretch jig was prepared from a rectangular aluminum bur measuring 1.6 mm × 3.7 mm, similar

Figure 1: High tension stress points created in the elastomer that ligate wire to a malposed and malaligned tooth.

to the dimensions of the slot base of a maxillary central incisor Gemini Metal bracket 0.022 inch slot (3M Unitek, South Peck Road, Monrovia, USA). The corners of the jig were rounded similar to the corners of the bracket slot base to prevent damage to and rupture of the elastomers. One end of the jig was designed tapered to facilitate placing and removing the samples [Figure 2].

The point stretch jigs consisted of a rail and 4 aluminum blocks. To create stretch and stress points in elastomers, 0.014 inch NiTi wires were used, which are commonly used wires for moderate to severe crowding in the early stages of orthodontic treatment.[11] In order to produce controlled stretching, the distance between the upper border of the aluminum block and the bar connected to the block was adjusted at 1 and 3 mm, depending on the experimental group involved [Figure 2].

The elastomers were placed with the twin bracket straight shooter ligature gun (TP Orthodontics, Inc., US) to maintain the consistency of stretching while placing elastomers on the storage jigs. The storage jigs were placed in plastic bottles containing artificial saliva, which was replaced weekly and were stored in an incubator at 37 ± 1°C. The specimens were retrieved from the containers and tested at each time interval.

All the elastomer groups were tested for force, TS and extension to TS on materials testing machine (model 10 KN, M350-10CT, Testometric Company, UK). The ligatures were stretched at a rate of 0.2 inches/min until rupture according to Kovatch *et al*. study.[12] As each elastomer was stretched, force (N) and extension (mm) were measured constantly and recorded. Force–extension curve was plotted by the WinTest Analysis Materials Testing software (Testometric Company, UK). The force at predefined length (depending on the stretching type test group), TS and extension to TS were obtained from the force-extension curve. The fixture of the testing machine was designed by the CAD-CAM technique and was manufactured from two equal-sized aluminum cubes, with two semi-circular rods, measuring 1.1 mm in radius). At the beginning of the test the two halves of the fixture were placed next to each other with no space between them, hence producing a circle with a diameter of 2.2 mm. The error was considered to be <0.1 mm at this stage.

To calculate the distance between two parts of fixture [Figure 3] at which the force levels of elastomeric modules are measured [X in Figure 3], the inner circumferences of the elastomer on the fixture of the testing machine were adjusted to match the inner circumferences of the specimens placed on the storage jigs of the relevant groups, All the measurements were made at 0.1 mm accuracy using the SOLIDWORKS 2011 software. The distance X was calculated for all groups using the formula below:

The circumference of the elastomer on the Storage Jig (2 [Tool Error: Lack of compliance of two parts of fixture is considered o.1 mm] +2 [The circumference of the Fixture Semi-Circle] = 2X

The distance X was calculated as 2, 2.5, and 3.5 mm for the uniform stretch, 1 mm point stretch and 3 mm point stretch groups, respectively. The forces of the tested specimens were recorded at zero at all the distances of 2, 2.5, and 3.5 mm so that it would be possible to calculate the remaining forces in all the stretch type groups.

SPSS software version 18 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis of data at a significance level of $P < 0.05$. Three-way ANOVA was used for analysis of data on quantitative variables of force, TS and extension to TS, followed by *post-hoc* Tukey tests.

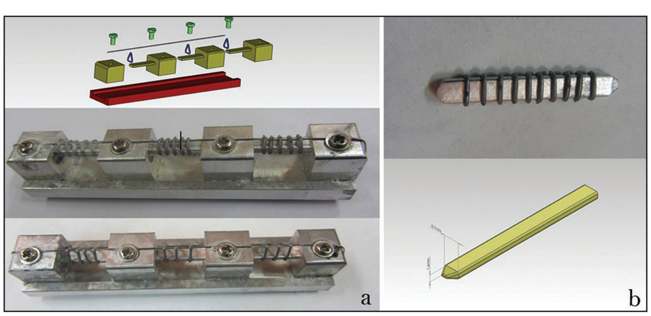

Figure 2: (a) Point stretch storage jig. (b) Uniform stretch storage jig.

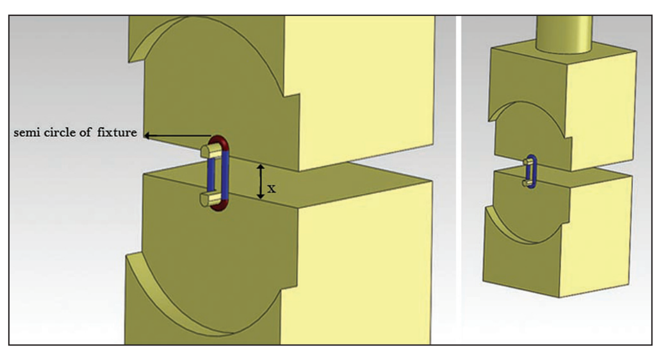

Figure 3: Fixture design and amount of elastomer stretching with SOLIDWORKS software.

RESULTS

ANOVA revealed that there were significant differences between the amount of forces, TS and extension to TS of different brand and stretch type groups of elastomers at each time intervals.

Force

The means of forces measured at zero, 24 h, 2 weeks, 4 weeks, and 8 weeks are presented in Table 1. The initial and final force level consistencies were not different in the two companies.

In the ligatures of both companies and three different stretch pattern groups, the greatest rate of force decay occurred during the first 24 h. However, this force decay in the Ortho Technology elastomers was 19-35% lower than that in Hangzhou Yamei elastomers.

Force decay from 4 to 8 weeks was statistically significant only in the Ortho Technology elastomers in the uniform stretch group (70 g) and in the Hangzhou Yamei elastomers in the 3 mm stretch group (40 g).

Tensile strength

The mean TS for all the experimental groups is presented in Table 2.

The TS of the Hangzhou Yamei elastomers was higher than the Ortho Technology elastomers in all the three stretch pattern groups at all the time intervals. The effect of the stretching pattern on the amount of TS was more noticeable in the Hangzhou Yamei elastomers. At each time interval, the maximum TS in the elastomers of each company were recorded in the nonuniform stretch pattern groups.

In the elastomers of both companies, the general trends of TS changes were decreasing; however, a small amount of increase in the TS was observed in some elastomers of both companies in the point stretch groups during the study.

Table 1: Mean force (*n*) and mean percentage of force loss over time for all test groups

Company	Stretch type	0	24 h	2 weeks	4 weeks	8 weeks
Ortho technology	Uniform stretch	3.1255±0.353	1.9306±0.095	1.6573±0.852	1.4571±0.225	0.741150±0.534
			38.3%	47%	52.4%	76.3%
	1 mm stretch	3.6685±0.485	2.3289±0.098	1.9310±0.142	1.7064±0.272	1.469±0.772
			36.5%	47.4%	53.5%	60%
	3 mm stretch	4.8249±0.519	3.2530±0.125	2.2157±0.162	1.6243±0.136	1.6142±0.234
			32.6%	54.1%	76.4%	76.6%
Hangzhou Yamei	Uniform stretch	5.0075±0.321	2.1323±0.321	1.4698±0.275	1.1775±0.549	1.1114±0.612
			57.5%	70.7%	76.5%	77.9%
	1 mm stretch	5.4982±0.495	1.7737±0.291	1.5455±0.095	1.537±0.283	1.6635±0.162
			67.8%	71.9%	72.1%	79.8%
	3 mm stretch	6.7290±0.412	2.9176±0.186	2.1183±0.147	1.4915±0.165	1.0817±0.354
			66.7%	68.6%	77.9%	84%

Table 2: Mean tensile strength (*n*) over the time for all test groups

Company	Stretch type	0	24 h	2 weeks	4 weeks	8 weeks
Ortho technology	Uniform stretch	17.710±0.81	16,570±0.94	16.488±0.32	16.329±1.39	15.770±2.45
	1 mm stretch		18.595±1.38	17.754±0.74	17.445±0.85	17.223±1.62
	3 mm stretch		21.092±1.52	17.797±1.20	17.654±1.35	17.237±1.11
Hangzhou Yamei	Uniform stretch	20.080±1.56	18.780±1.88	18.060±1.36	17.760±1.52	17.260±1.36
	1 mm stretch		19.875±0.68	18.344±1.23	19.107±1.30	18.170±1.39
	3 mm stretch		21.560±0.927	21.362±1.73	20.920±1.91	19.378±1.119

Table 3: Mean extension to tensile strength (mm) over the time for all test groups

Company	Stretch type	0	24 h	2 weeks	4 weeks	8 weeks
Ortho technology	Uniform stretch	10.391±0.25	11.685±0.85	11.240±0.23	11.414±1.00	11.9±1.10
	1 mm stretch		11.397±0.51	11.960±0.65	12.379±0.77	12.576±0.22
	3 mm stretch		11.563±0.76	12.420±0.86	13.092±0.40	13.633±1.5
Hangzhou Yamei	Uniform stretch	11.465±0.33	1.550±0.95	13.870±0.82	14.160±0.96	13.087±0.45
	1 mm stretch		13.850±0.66	14.550±0.65	14.660±0.68	15.120±0.79
	3 mm stretch		13.766±0.56	15.350±0.65	14.21±0.62	14.800±0.50

Extension to tensile strength

The mean extensions to TS for all the experimental groups are presented in Table 3.

From week 4-8, changes in the extension to TS were not statistically significant in any of the test groups, except in the uniform stretch group in Hangzhou Yamei elastomers where extension to TS decreased (1 mm).

At each time interval and in all the three types of stretch pattern groups, extension to TS of Hangzhou Yamei elastomers was significantly higher. During the whole study, the extension to TS increased in general in the elastomers of both companies; however, in some experimental groups a decrease in extension to TS was observed.

DISCUSSION

The results of this study showed a significant relationship between the stretching pattern and the brand of gray elastomeric ligatures on one hand and the amount of force, TS and extension to TS on the other hand during an 8-week period.

Since an elastomer might be deformed during a stretch test for the measurement of force, in the present study, each elastomeric sample underwent a stretch test only once. This study design made it possible to evaluate the three variables of force, TS and extension to TS, simultaneously.

The force decay pattern in this study was similar to that in other studies on elastomeric ligatures and chains, indicating a significant decrease in force during the first 24 h and less force decay or relative stability at subsequent intervals.[1,13-19] Based on the results of our study, the amounts of remaining force, TS and extension to TS were higher in the elastomers of both companies in the 1 and 3 mm stretch groups compared to the uniform stretch group at all the time intervals. The elastomers in the point stretch groups exhibited higher remaining forces at the end of an 8-week period due to higher amounts of initial force despite higher percentages of force decay at some, time intervals.

For comparing the results of different studies, it is important to bear in mind that the amount of elastomer stretching on the holding jig and during force measurements affect the amount of forces reported. In our study to determine the amount of stretching during force measurement procedure, computer software was used for measuring the circumference of the elastomers in different stretching pattern groups. In this method, the circumference of elastomers on the fixture in each group corresponds to the circumference of the elastomers on their relevant holding jigs. In a study by Taloumis *et al*. the means of initial forces (585-1036 g) and residual forces after 4 weeks (198-466 g) in all the elastomers were higher than those in the present study. In their study, the amount of force was calculated at a stretch length of 5.5 mm, and the ligatures were stretched over a stainless steel dowel measuring 4 mm in diameter.[1] In this study, similar to a study by Lu *et al*.,[20] elastomers which had a higher initial force, exhibited more force decay, especially during the first 24 h.

Evaluation of the amount and pattern of TSs changes in the 1 and 3 mm stretch groups showed that when the elastomers underwent point stretching, their TSs increased, especially during the first 24 h. It is desirable that a stretched elastomer possesses high TS to avoid premature rupture. The differences in TS found between different stretching patterns may reflect variations in the orientation of molecular rearrangement of materials. Higher values of the mechanical properties are associated with the crystalline structure of polymers. These effects may provide some increase in the polymer crystallinity and mechanical properties when polyurethane chains are stretched.[6] A limited number of studies have been carried out on the TS and extension to TS of elastomeric ligatures. Lam *et al*. evaluated the TS and the extension to TS of elastomeric ligatures manufactured by Ormco and Unitek companies from 0 to 12 weeks.[10] From 0 to the 8 weeks interval an increase in extension to TS and a decrease in TS were observed. The results of that study and this study showed that the TS and extension to TS could undergo changes independent from one another, which might be attributed to the relative stability of material toughness.

As there is little decrease in the TS of elastomers between 4 and 8 weeks, which is not significant from a clinical point of view, there is no reason to worry about the possibility of their rupture or separation of the wire from the bracket in this time interval. If there is no concern about bacterial accumulation and reloading concept Absence of any clinically significant changes in the TS and the extension to TS after 4 weeks and a residual force of 127 ± 35 g at the end of week 8 in the elastomers evaluated, indicated the possibility of scheduling treatment sessions longer than 4 weeks intervals during the first stage of fixed orthodontic treatment. Contrarily, given the 68.1% ± 10% force decay at the end of week 4 and the 75.7% ± 8% decrease at the end of week 8, the elastomeric modules are not good candidates for remaining in oral cavity more than 4 weeks in the final stages of fixed orthodontic treatment, in which the wire should be completely and actively seated in the bracket slot.

Since an *in vivo* study has shown that force decays of elastomers in the oral cavity are significantly higher than of those *in vitro*, the results of *in vitro* studies cannot be easily extended to clinical situations.[21] This emphasizes the necessity of performing more *in vitro* and *in vivo* researches to measure the residual forces in elastomeric ligatures and to measure the amount of required ligation forces for different kinds of tooth movement in various stages of orthodontic treatment. Besides, all the results of our study are based on the hypothesis of preserving the static status of the teeth during the duration of the experiment which is not the case in real clinical practice. More precise and sophisticated modeling methods are necessary to simulate more precisely the dynamic relationship between wire, bracket, and ligature during tooth movement.

Peterson reported that if ligation or normal forces decrease, there will be a corresponding decrease in frictional resistance.[22] In addition, Bortoly *et al*. reported a strong relationship between tensile forces and frictional forces of elastomers. In other words, higher forces in elastomers result in higher frictional forces in the system, decreasing tooth movement rate in early stages of treatment.[23] Decreasing the amount of ligation force and frictional resistance will result in increasing the amount of residual aligning forces which is the rationale for the superiority of self-ligating systems in the early stages of treatment. Another drawback of higher initial ligation forces in the first treatment session is the possibility of bracket debonding due to the lack of maximum bond strength immediately after bonding of brackets. Therefore, if there is no concern about bacterial accumulation or reloading concept, during the early stages of treatment, elastomers with a lower initial ligation force and a lower force decay rate are better choices compared to elastomers with higher initial ligation forces.

The results of this study indicates that for selecting a ligation module, orthodontists should consider the amount of initial force, force decay rate over time and the required ligation force in terms of the stage of treatment, in addition to the price, reputation of the trademark and color of the elastomeric ligatures. Under some clinical conditions, such as torque and rotation correction, higher ligation forces are required.[9,24] However, studies on self-ligating brackets have shown the advantages of light forces in the early stage of orthodontic treatment.[25,26]

CONCLUSION

- In the elastomers evaluated in this study, the maximum force decay occurred during the first 24 h, continuing at a lower rate for 8 weeks.
- After 8 weeks, the maximum force decay occurred in the gray elastomers of both Hangzhou Yamei and Ortho Technology companies in the groups undergoing 3 mm of stretching.
- The extension to TS, the amount of residual force and the TS were higher in the elastomers of point stretch groups compared to uniform stretch groups at all the time intervals.
- Due to the absence of a significant decrease in the TS and the extension to TS in the Hangzhou Yamei and Ortho Technology elastomers, it is unlikely that these elastomeric ligatures rupture if the appointments are delayed up to a period of 8 weeks.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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