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Tensile properties of orthodontic elastomeric ligatures

F Ahrari, T Jalaly, M Zebarjad¹

Dental Research Center, Department of Orthodontics.	ABSTRACT
School of Dentistry, Mashhad University of Medical Sciences, ¹ Department of Metallurgy.	Context: Tensile properties of elastomeric ligatures become important when efficiency of orthodontic appliances is considered.
School of Engineering, Ferdosi	Aims: The aim of this study was to compare tensile strength, extension to tensile strength,
University, Mashhad, Iran	toughness and modulus of elasticity of elastomeric ligatures in both the as-received condition and after 28 days of immersion in the simulated oral environment. Furthermore, the changes
	that occurred in tensile properties of each brand of ligatures after 28 days were evaluated.
	Setting and Design: Experimental-laboratory based.
	Materials and Methods: Elastomeric ligatures were obtained from different companies and
	their tensile properties were measured using \angle wick testing machine in both the as-received
	Statistical Analysis Head: The data were analyzed using independent complet tests, analysis
	of variance and Tukey tests.
	Results: After 28 days, all the ligatures experienced a significant decrease in tensile strength,
	extension to tensile strength and toughness ($P < 0.05$), whereas modulus of elasticity increased
	in some groups and decreased in others. There were significant differences in tensile properties
	of different brands of ligatures in both conditions ($P < 0.05$), with the exception of modulus of electricity after 28 days
	Conclusions: The decrease in strength properties of elastomeric lightures shows that they
	should be replaced at each appointment to reduce the risk of rupture. There are significant
Received : 01-01-09	differences in tensile properties of different brands of ligatures, which should be considered
Review completed : 30-03-09	during selection of these products.
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	Key words: Elastomeric ligature, tensile properties, tensile strength, toughness, modulus of
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One of the most common methods of securing archwires to orthodontic brackets is the application of elastomeric ligatures (modules). Elastomeric ligatures are synthetic elastics made of polyurethane materials; however, the exact composition is proprietary information.^[1,2] Although these ligatures show some disadvantages such as microbial colonization^[3,4] and sliding resistance,^[5] their advantages such as quickness of application, patient comfort, and variety of colors^[6] have resulted in greater popularity than stainless steel ties. In addition, elastomeric ligatures are much less expensive than self-ligating clips.

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One of the tensile properties of elastomeric modules important for orthodontists is tensile strength (TS). TS is defined as the maximal stress required to fracture a material.^[7] Another property of elastomeric modules is extension to TS, which is measured as the amount of extension necessary to reach the TS. Ligatures with a high extension to TS (ie, they should be stretched a long distance to reach the TS) are more difficult to break, while ligatures with low extension to TS are easily broken.^[8] Another tensile property of elastomeric ligatures is toughness. Toughness is described as the amount of energy required to fracture a material and can be measured as the total area under the force-extension curve from zero stress/force to the fracture strength.^[7] It is dependent on both the TS and extension to TS.^[8] Another important property of elastomeric ligatures is the modulus of elasticity, which is measured by the slope of the stress-strain curve from zero point to proportional limit.^[7] The modulus of elasticity shows the amount of force per unit extension and describes the stiffness of a material. Ligatures with a high modulus of elasticity exert more force on archwire-bracket combination and vice versa.

If elastomeric modules lack adequate tensile properties, clinical application will be difficult and time-consuming, and they may tear during engagement to the brackets or between patient's appointments. The latter may cause undesirable tooth movement and prolong orthodontic treatment. Another problem is that the ligatures may exert

Address for correspondence: Dr. Farzaneh Ahrari, E-mail: ahrarif@mums.ac.ir

excessive force during placement onto the brackets and cause bracket detachment. This is more probable when brackets are bonded a few minutes ago and bond strength has not reached the maximal value. In addition, the force of ligation contributes to friction and consequently counteracts free sliding.

There has been extensive research on the effects of time,^[9-13] temperature,^[2,14] fluoride treatment,^[15] pH,^[14,16] water sorption,^[17] prestretching^[1,12,14,15,18] and environmental conditions^[9,15,19,20] on force delivery, force degradation, permanent deformation and strength of elastomeric chains and orthodontic elastics, but there have been few reports on the behaviors of elastomeric ligatures.^[6] Failure load forces and frictional resistance of 5 types of new and used elastomeric ligatures were evaluated by Dowling et al.^[21]The results revealed that rectangular grey modules produced by die-punching were 50%-80% stronger than other groups, while the clear modules demonstrated the lowest failure forces. In addition, failure load force of all types of ligatures decreased following immersion in the simulated oral environment. Lam et al.,^[8] evaluated TS and extension to TS of clear and colored elastomeric ligatures obtained from Ormco and Unitek at different time intervals. The results showed that tensile strength of Unitek ligatures was slightly little more than Ormco ligatures, but all the ligatures tested experienced an overall decrease in the TS during the study. Extension to TS, which was evaluated for the first time in this study, increased gradually over time.

During sliding mechanics, friction is a major consideration because it counteracts the applied force and can lead to anchorage loss,^[22] reduce the speed of tooth movement^[23,24] and have a negative effect on treatment outcome and duration.^[25] One of the important factors that affects friction is the ligation material and methods.^[22,26-33] A single elastic module produces a ligation force of 50-150 g.^[34] Although loosely tied stainless steel ligatures produce less friction than elastomeric modules,^[22,28,30,31] they produce variable ligation forces and are time-consuming to place,^[35] so they are less popular than elastomers.^[30] To reduce or eliminate friction, passive elastomeric ligatures^[30,36-39] and self-ligating brackets systems^[31,34,40-43] have been proposed as a replacement for conventional modules.

We have found that in the available literature there are few studies about TS and extension to TS of elastomeric ligatures and no report about the toughness and modulus of elasticity of these modules. Therefore, the purpose of this study was to compare tensile properties (tensile strength, extension to tensile strength, toughness and modulus of elasticity) of several brands of elastomeric ligatures in both the as-received condition and after 28 days of immersion in the simulated oral environment. Furthermore, the changes that occurred in the tensile properties of each brand of ligatures after immersion in the simulated oral environment were evaluated.

MATERIALS AND METHODS

Injection-moulded clear elastomeric ligatures obtained from American Orthodontics, Ortho Technology, GAC, All Star and Dentaurum were selected. The internal and external diameters of all these ligatures were the same. Fifteen samples from each company were evaluated for tensile properties in each of the two following conditions: as-received condition and after 28 days of immersion in the simulated oral environment. To hold ligatures in artificial saliva, seven metal jigs were fabricated with a cross-sectional diameter equivalent to that of a stainless-steel standard edgewise maxillary central incisor bracket (0.018 inch slot; Dentaurum, Ispringen, Germany). A maxillary central incisor bracket was bonded on one end of each jig and the other end of the jig was tapered to facilitate the application and the removal of ligatures. Elastomeric modules were initially engaged over the bracket on the jig and then transmitted to the lower part of the jig to simulate the clinical application and stretching of a ligature to a bracket [Figure 1]. The jigs were stored in individual glass bottles containing artificial saliva and stored for 28 days at 37°C. The artificial saliva used in this study consisted of 1 g sodium carboxymethylcellulose, 4.3 g xylitol, 0.1 g potassium chloride, 5 mg calcium chloride, 40 mg potassium phosphate, 1 mg potassium thiocyanate and 100 g distilled deionized water. The artificial saliva was changed twice daily during the period of the experiment. After 28 days, the jigs were thermocycled between 5°C and 55°C for 500 cycles with a dwell time of 30 seconds per bath. Then elastomeric ligatures were removed from the jigs and their tensile properties were evaluated.

The tensile force was measured on the Zwick testing machine (Zwick GmbH & Co, Ulm, Germany). Using U-shaped loops which were formed from 0.8-mm stainless steel wire, elastomeric ligatures could be stretched on the testing machine until they were broken [Figure 2]. This was carried out with a cross head speed of 5 mm/min according to the recommendation of Kovatch et al.[44] Load-extension curve of each module was recorded graphically. Using these curves, TS, extension to TS, toughness and modulus of elasticity of the ligatures were determined. In this study, we refer to TS as failure load force of elastomeric ligatures because the cross-sectional areas of all the ligatures were the same. Fifteen elastomeric modules from each company were tested in the as-received condition. Then, the 15 used modules, which had been stored in artificial saliva for 4 weeks at 37°C followed by thermocycling, were removed from the jigs and transferred to the testing machine.

Statistical analysis

For all variables, presumptions of normality were analyzed by the Kolmogorov-Smirnov test. At first, a two-way analysis of variance (ANOVA) was used with brands and aging (before and after 28 days) as the discriminating variables, but there was a significant interaction between the two variables, making it necessary to evaluate these variables separately. Therefore, one-way ANOVA was used separately to compare means of TS, extension to TS, toughness and modulus of elasticity of different elastomeric ligatures in both the asreceived condition and after immersion in the simulated oral environment. Post hoc Tukey pairwise comparison tests were performed to identify significant between-group differences. Independent sample *t*-tests were used to study differences between the new and used states for each group of ligatures.

RESULTS

The means of tensile properties of each brand of elastomeric ligatures in the as-received condition and after 28 days of immersion in the simulated oral environment are presented in Table 1.

The results of independent sample *t*-tests indicated that TS, extension to TS and toughness of all groups decreased significantly after immersion in the simulated oral environment (P < 0.05). Modulus of elasticity increased significantly in American Orthodontics and Ortho Technology modules and decreased significantly in Dentaurum modules (P < 0.05). Variations in modulus of elasticity of the other groups were not statistically significant (P > 0.05).

ANOVA revealed that there were significant differences in all the tensile properties of different modules in the as-received condition (P < 0.05). A similar analysis of the used groups revealed that there were significant differences in TS, extension to TS and toughness of different groups of ligatures (P < 0.05), but the modulus of elasticity was not statistically different after 28 days of storage (P = 0.05).

Regarding TS [Figure 3] in the as-received condition, American Orthodontics, All Star and Dentaurum ligatures had the greatest mean tensile strength, and showed no difference to each other; next was GAC, and the last was Ortho Technology modules, which demonstrated the lowest mean tensile force. After 28 days of storage, American Orthodontics, Dentaurum, All Star and GAC ligatures had the greatest mean TS, with no difference to each other, followed by Ortho Technology ligatures, which had the lowest mean TS.

Regarding extension to TS [Figure 4] in the as-received condition, GAC and Dentaurum ligatures had the greatest mean extension to TS followed by American Orthodontics, All Star and Ortho Technology ligatures, which were not statistically different from each other. After 28 days of storage, Ortho Technology ligatures showed the lowest mean extension to TS and the other groups were not statistically different.

Regarding toughness [Figure 5] in the as-received condition, Dentaurum modules showed the highest and Ortho Technology modules showed the lowest mean toughness. After immersion in the simulated oral environment, American Orthodontics and GAC ligatures had the greatest and Ortho Technology and All Star ligatures showed the lowest mean toughness.

Regarding modulus of elasticity [Figure 6], American Ortho dontics and Ortho Technology modules showed the lowest and Dentaurum modules showed the highest mean modulus of elasticity in the as-received condition. After immersion in the simulated oral environment, no significant difference was found between the five groups with respect to the modulus of elasticity.

DISCUSSION

The mean TS of elastomeric modules in the as-received condition ranged from 15.1 N for Ortho Technology to 22.5 N for American Orthodontics modules. In one study,^[8] the values of 19.2 N and 21.7 N were gained for TS of Ormco and Unitek ligatures, respectively. In another study,^[21] the TS of clear and colored injection moulded elastomeric ligatures obtained from A-Company were between 15.2 N and 19.8 N. These differences could be attributed to the different brands of ligatures or the difference in research

Table 1: Comparison of mean (SD) tensile properties of elastomeric ligatures in the as-received condition and after 28 days of immersion in the simulated oral environment

Group	Test condition	Tensile strength (N) mean (SD)	Extension to tensile strength (mm) mean (SD)	Toughness (N.mm) mean (SD)	Modulus of elasticity (N/mm) mean (SD)
American Orthodontics	As-received	22.56 (1.37)	11.88 (0.47)	121.92 (5.1)	1.11 (0.06)
	After 28 days	18.04 (1.31)	10.33 (0.68)	96.49 (11.17)	1.49 (0.07)
Ortho Technology	As-received	15.12 (1.19)	11.3 (0.82)	89.62 (13.64)	1.17 (0.07)
	After 28 days	11.85 (1.29)	8.45 (0.95)	53.88 (11.46)	1.36 (0.07)
GAC	As-received	20.11 (1.57)	13.19 (2.04)	124.12 (20.64)	1.54 (0.08)
	After 28 days	15.9 (2.12)	10.17 (2.29)	84.06 (26.92)	1.48 (0.2)
All Star	As-received	22.44 (2.62)	11.52 (0.95)	109.13 (10.87)	1.48 (0.17)
	After 28 days	16.43 (3.41)	9.15 (1.53)	68.39 (20.45)	1.38 (0.14)
Dentaurum	As-received	22.31 (1.16)	12.36 (0.87)	152.86 (20.33)	2.12 (0.11)
	After 28 days	17.5 (1.97)	9.46 (1.25)	74.62 (11.06)	1.45 (0.16)



Figure 1: Elastomeric ligatures on the holding jigs



Figure 2: Stretching elastomeric modules on the testing apparatus



Figure 3: Mean tensile strength of experimental groups in the as-received condition and after 28 days immersion in the simulated oral environment (G1 = American Orthodontics; G2 = Ortho Technology; G3 = GAC; G4 = All Star; G5 = Dentaurum)



Figure 5: Mean toughness of experimental groups in the as-received condition and after 28 days immersion in the simulated oral environment (G1 = American Orthodontics; G2 = Ortho Technology; G3 = GAC; G4 = All Star; G5 = Dentaurum)



Figure 4: Mean extension to tensile strength of experimental groups in the as-received condition and after 28 days immersion in the simulated oral environment (G1 = American Orthodontics; G2 = Ortho Technology; G3 = GAC; G4 = All Star; G5 = Dentaurum)



Figure 6: Mean modulus of elasticity of experimental groups in the as-received condition and after 28 days immersion in the simulated oral environment (G1 = American Orthodontics; G2 = Ortho Technology; G3 = GAC; G4 = All Star; G5 = Dentaurum)

methodology. In the aforementioned studies, ligatures were stretched with the cross head speed of 25 mm/min^[8] and 50 mm/min^[21] until rupture, whereas in the present study we used the cross head speed of 5 mm/min. This may cause differences in the values of tensile properties, because elastomers are sensitive to the speed of extension.^[44] After immersion in the simulated oral environment, all of the ligatures showed 20-27% decrease in TS. This is similar to the findings of Lam *et al.*^[8], who reported an overall decrease in the TS of Ormco and Unitek modules over time. Similarly, Dowling *et al.*,^[21] observed 10-20% reduction in failure load forces of cut ligatures after 4 weeks of immersion in the simulated oral environment.

The extension to TS of elastomeric ligatures shows the distance that these modules could be stretched before tearing. The extension to TS of ligatures in this study ranged from 11.3 mm for Ortho Technology to 13.1 mm for GAC modules. These values are somewhat higher than those reported in a previous study^[8] (6.9-10.4 mm). Again, this may be attributed to the different brands of ligatures or the difference in research methodology. After immersion in the simulated oral environment, the extension to TS of all ligatures decreased 13-26%. This finding is not consistent with the results of Lam *et al.*,^[8] who showed 7-22% increase in extension to TS of Ormco and Unitek ligatures in 4 weeks.

The toughness values of elastomeric ligatures in the as-received condition ranged from 89.6 N.mm for Ortho Technology to 152.8 N.mm for Dentaurum modules. All groups of ligatures showed 21-51% decrease in toughness after immersion in the simulated oral environment. According to our data, toughness of elastomeric ligatures has not been evaluated directly in previous studies. Lam *et al.*,^[8] reported that during 4 weeks, the mean TS of elastomeric ligatures decreased by approximately 7-22%, while the extension to TS increased by almost the same percentage. Thus, the authors argued that the toughness of these ligatures remained unchanged from 0 to 4 weeks.

The decrease in strength properties of elastomeric ligatures may be attributed to the effects of humidity and temperature that deteriorate the polymeric structure.^[6,17] This decrease indicates that elastomeric ligatures should be replaced at each appointment to reduce the risk of tearing.

The mean modulus of elasticity of ligatures in the as-received condition ranged from 1.11 N/mm for American Orthodontics to 2.12 N/mm for Dentaurum ligatures. After immersion in the simulated oral environment, modulus of elasticity increased in some groups and decreased in others. These changes are probably related to the effects of humidity and temperature, but since the exact formula of elastomers is a commercial secret, it is not possible to define exactly why these factors have increased the modulus of elasticity of some

groups and decreased those of the others. The importance of the modulus of elasticity is that it shows the amount of force per unit extension. Hence, the more the modulus of elasticity, the more the force that the ligature exerts on bracket-archwire combination and the more will be the probability of bracket detachment. In addition, reducing the friction of ligation is desirable in sliding mechanics, as it facilitates tooth movement. Therefore, it is better to use ligatures with less stiffness immediately after bonding and in sliding mechanics. On the other hand, performing some orthodontic movements such as torque and rotational correction requires large rotational moments and higher amounts of forces; thus, ligatures with higher modulus of elasticity are more suitable for these applications. Nevertheless, in one study^[45] elastomeric ligatures were not efficient in holding archwires in bracket slots when large rotational moments were applied.

According to our data, there is no study about the modulus of elasticity of elastomeric ligatures. Wong^[19] studied the modulus of elasticity of 3/16 latex elastics, Unitek chain and Ormco Power Chain and stated that the findings can only serve as a guide to determine what force could be obtained when these are applied to the teeth. Russell *et al.*,^[46] studied the mechanical properties including modulus of elasticity of latex and non-latex orthodontic elastics obtained from GAC, and Masel and concluded that the clinical choice of elastics should be based on the patient's medical history and the mechanical properties of the elastics, which is influenced by the type of material and the company that produced it.

Comparison of tensile properties of different brands of ligatures showed that there were significant differences in tensile properties of these modules in both the as-received condition and after 28 days of immersion in the simulated oral environment with the exception of modulus of elasticity after 28 days. Regarding TS, Ortho Technology modules showed the lowest TS in both conditions and the other groups were relatively the same. Generally a higher amount of TS is more desirable because it indicates that the structure can withstand a higher amount of force before breakage. However, this property should be considered with respect to other tensile properties.

Although there were significant differences in the extension to TS of different ligatures, the numerical differences between groups were relatively small and under the study conditions, it is difficult to determine which brand of ligatures is superior to the others in this aspect. However, in clinical situations these modules may be stretched faster and consequently the differences between groups would be more apparent.

Regarding toughness, Ortho Technology ligatures showed the lowest toughness in both conditions. Dentaurum ligatures had the highest mean toughness in the as-received condition but they experienced a remarkable decrease in toughness over time. Toughness is defined as the energy required for fracturing a material. Therefore, the ligatures with lower toughness require less energy to break and have a higher probability of rupture during clinical application or between patient's appointments as a result of chewing or oral hygiene habits.

Comparison of modulus of elasticity of different brands of ligatures in the as-received condition indicated that American Orthodontics and Ortho Technology ligatures, which had the lowest modulus of elasticity are suitable to use immediately after bonding and in-sliding mechanics, whereas Dentaurum ligatures are not suitable to use immediately after bonding.

Usually in selecting elastomeric ligatures numerous factors are considered, among which one can mention size, color and cost of these products. Regarding the importance of tensile properties of these modules in efficiency of orthodontic treatment, it seems reasonable for orthodontists to consider these properties, too. It is also suggested that manufacturers offer the relevant data to their customers.

Considering the number of variables evaluated in this study, it is difficult to conclude about the best elastomeric ligature from the point of tensile properties. In fact, different ligatures may have relative preferences in different conditions. However, under the study conditions, Ortho Technology modules had the lowest strength properties but because of the lowest modulus of elasticity, these ligatures are suitable for sliding mechanics and immediate application after bonding. American Orthodontics ligatures exhibited the combination of higher strength properties and the lowest modulus of elasticity and altogether had the best tensile properties. Dentaurum ligatures showed the highest modulus of elasticity; therefore, in comparison with other groups, these are not suitable for use immediately after bonding.

The results of this study are related to clear elastomeric ligatures in the simulated oral environment. Although the findings of this study can serve as a good guide in anticipating clinical behaviors of ligatures tested, it is important to care about extrapolating *ex vivo* results to clinical condition.

CONCLUSIONS

- After 28 days of immersion in the simulated oral environment, all ligatures tested experienced a decrease in strength properties (TS, extension to TS, and toughness), whereas modulus of elasticity increased in some groups and decreased in others. The decrease in strength properties of elastomeric ligatures shows that it is better to replace them at each appointment to reduce the risk of rupture.
- There were significant differences in tensile properties of these ligatures in both the as-received condition and after 28 days of immersion in the simulated oral

environment, with the exception of modulus of elasticity after 28 days. Regarding the importance of tensile properties of these modules in efficiency of orthodontic treatment, it is suggested that orthodontists consider these properties during selection of the products they use and manufacturers offer the relevant data to their customers.

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