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In vitro Mechanical Behavior of Elastic Distal Chain and Ligature Immersed in Antiseptics

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ABSTRACT

Introduction. Elastomeric chains and tiebacks are used in orthodontics during the space closure phase. Hence, it is necessary to use the most efficient material for this purpose. **Objective.** This research aimed to evaluate the loss of strength in elastomeric chains (3M Unitek) and tiebacks (3M Unitek) on days 0, 7, 14, and 21, as well as the effects of 0.12% chlorhexidine and triclosan on their mechanical behavior. **Materials and methods.** The sample consisted of 90 elastomeric chains and 90 tiebacks. These chains were brought under stress tests at a constant distance. **Results.** The differences in strength between the chain measurements and tieback exposed to the three solutions were not statistically significant (p> 0.05). Significant changes were identified among the different time intervals. The elastomeric chain presented a higher mean value

of strength loss in the first 7 days and remained constant until 21 days, with biological forces. The tieback showed loss of strength up to 14 days, from that moment on, the strength is no longer functional for tooth movement. **Conclusion.** Time is the most important factor in elastomer strength loss. The force maintained in the elastomeric chain is more constant and biological in comparison with the tieback.

Keywords: Elastomeric chain, tieback, *in vitro*, chlorhexidine, triclosan.

INTRODUCTION

One of the most time-consuming phases in orthodontic treatment is the space closure phase in cases of premolar extractions. Accelerating this stage by using the most efficient material will reduce total treatment time thus increasing patient cooperation and decreasing possible side effects[1]. The ideal biological forces for these dental movements are based on exerting light and continuous forces; a common, practical, and inexpensive way to perform these movements can be carried out with sliding techniques and the aid of elastomeric materials[2], for example, with elastomeric chains or elastic distal ligature.

In the mid-sixties, elastic materials began to be used to maintain the archwire within the bracket slot, which led to the development and patenting of an elastomeric material process; later the Unitek company purchased the products and began marketing them to orthodontists in 1968[3]. Thus, elastomeric chains were introduced, offering benefits such as low cost, ease of use and requiring minimal patient cooperation, if any.

In 1970 Andreasen and Bishara compared latex and Alastik Unitek elastics concerning space closure and found that 74% of their initial strength was lost 24 hours after placement, while latex elastics lost only 42%[4]. In 1975 Hershey and Reynolds compared three types of chains and found that after 24 hours 50% of the initial strength had been lost while a remnant of 40% of the initial strength remained after four weeks. In addition, they noted that the most constant strength was given by chains manufactured by stamping and not by injection[5]. By 1976, Wong conducted a study of two different chains, immersing them in water at 37°C, and reported that in the first 24 hours, a loss of 50 to 75% of the initial strength occurred[6]. Kovatch *et al.* evaluated the initial strength levels of Unitek Alastiks that were stretched to 30% of their original size and recommended slow stretching of the modules for their placement[7].

In 1978 Ash and Nikolai compared the loss of strength of open chains *in vivo*, in water, and air, and concluded that *in vivo* chains show a greater loss of strength after 30 minutes than those in air[8]. They assumed that oral cavity factors modify the degradation rates of the chains. However, both maintained force levels of 160 g, which according to Mohammed *et al*.[9], and to Baty *et al*., is a force strong enough for tooth movement[10]. Mousavi performed a study in which he compared elastomeric chains of different lengths: closed, intermediate, and open; and concluded that the closed chain presents better physical behavior, maintaining the initial force longer than the intermediate and open chain[2]. Baty *et al*.[10] and Von Fraunhofer *et al*.[11] compared colored chains and gray chains and concluded that the colored chains needed to be stretched more to obtain optimum levels of strength.

The importance of knowing the factors that may modify the mechanical behavior of elastomeric materials lies in being able to choose the material that provides the most efficient

treatment and how long it can be maintained with useful biological forces for the space closure phase.

MATERIAL AND METHOD

The study was conducted at the Post-Graduate Studies and Research Division (DEPeI, its acronym in Spanish) of the Universidad Nacional Autónoma de México (i. e., DEPeI UNAM), in the Dental BioMaterials Laboratory. We used grey closed Alastik Chain 3M Unitek elastomeric chains made by stamping with batch IC3WI and grey Alastik Silver Easy-To-Tie Ligature 3M Unitek modules made by injection with batch HM9VS (Figure 1). The inclusion criteria were all closed chains and elastic modules corresponding to the brand, color, size, and lot mentioned above. The exclusion criteria were all chains and modules that did not correspond to that brand, color, size, and lot, those that were damaged or damaged to the naked eye, or that the packaging had been opened.

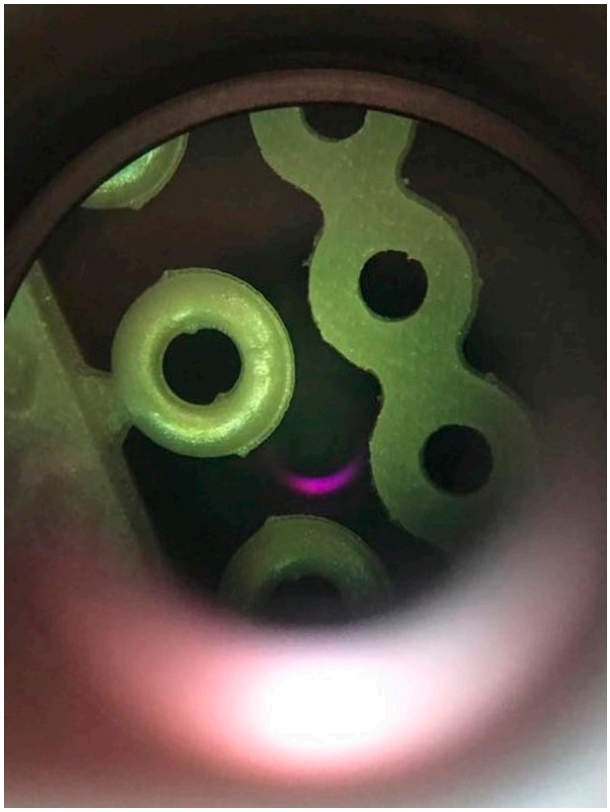


Figure 1. Optical microscopy image of 3M elastomeric module (injection) and 3M elastomeric chain (stamped).

To establish the distance at which the samples would be stretched, a measurement was taken in 41 patients of the Orthodontic Clinic, DEPeI, UNAM, with orthodontic treatment ready to begin the space closure phase. This measurement was taken from the hook of the band or tube of the upper first molar at half the distance between the canine and lateral of the

same quadrant, using a Mitutoyo digital caliper in both quadrants. Eighty-two measurements were obtained; the mean was 25.6mm. Six transparent acrylic bases were made where 32 pairs of metallic posts made of 0.045" stainless steel were placed at a distance of 25.6mm between each of them. The immersion solutions used (two oral antiseptics and artificial saliva) were Bexident® Gingival Mouthwash Chlorhexidine 0.12%, Bexident® Triclosan Gingival, and artificial saliva elaborated in the Dental Biomaterials Laboratory, DEPeI, UNAM. The pilot tests were performed using a Macmesin AFG 50N digital dynamometer, to establish forces between 300-400 gr[12]; using seven links of the chains and in the distal ligature a total distance of 23.1mm, with metallic ligature of 0.010" SS caliber of the TP Orthodontics, Inc® brand.

The tests were run in an Instron machine at a loading speed of 0.5mm/min with the unit of measurement in Newtons (1N= 102 grams force); 90 samples of chain and 90 of ligature, each sample was placed in the Instron machine, and the tensile strength was measured when stretched at a distance of 25.6mm. Once the measurement was done, they were placed on the acrylic base (Figure 2). Of the 90 chain and ligature samples, 30 from each group remained immersed in artificial saliva for 21 days; 30 in 0.12% chlorhexidine and 30 in triclosan for 21 minutes respectively, then they were pressure-rinsed with purified water and placed in artificial saliva for 21 days. All the samples remained in a temperature-controlled environment at 37°C in a Red Line by Binder model oven. Tension measurements were taken at baseline, 7 days, 14 days, and 21 days.

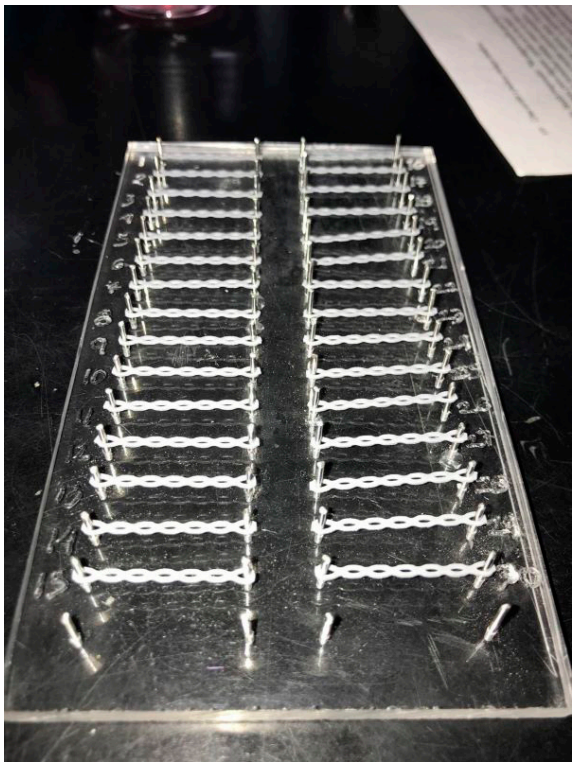


Figure 2. Samples of elastomeric chain placed on acrylic base.

To compare the percentage of strength loss among the three groups, a one-way analysis of variance (ANOVA) (factor) was used. To evaluate the percentage of loss between the measurements at 7, 14, and 21 days for each solution, the repeated measures ANOVA analysis was used.

In both cases the Bonferroni post hoc test was used, and a significance level of p<0.05 was established, and the SPSS® 18.0 statistical package was used.

RESULTS

The loss of strength in the elastomeric chain was not different for having been immersed in saliva, chlorhexidine, or triclosan (Table 1), however, when assessing the loss of strength over time of the elastomeric chain for each solution, a statistically significant trend of decrease is shown. For the chains immersed in saliva, differences were found between the baseline measurement and at 7, 14, and 21 days; for chlorhexidine and triclosan, all comparisons were statistically significant, except between the 7 and 14-day intervals (Table 2).

Table 1.
Effect of three solutions on elastomeric chain strength loss.

Solutions		Strength loss in Mega Pascals Mean difference (CI 95 %)	p
Saliva [a]	**Triclosan [b]**	-0.70 (-1.53-.013)[ab]	0.098
	Clorhexidine [c]	-0.001(-.085-.082)[ac]	0.974
Triclosan b	**Saliva [a]**	0.070 (-.013-.153) [ba]	0.098
	Clorhexidine [c]	0.069 (-.014-.152) [bc]	0.104
Clorhexidine c	**Saliva [a]**	0.001 (-.082-.085) [ca]	0.974
	Triclosan [b]	-0.069 (-.152-.014)	0.104

ANOVA test, significance p<0.05

Table 2.
Comparison of the effect of three solutions at four-time measurements on elastomeric chain strength loss.

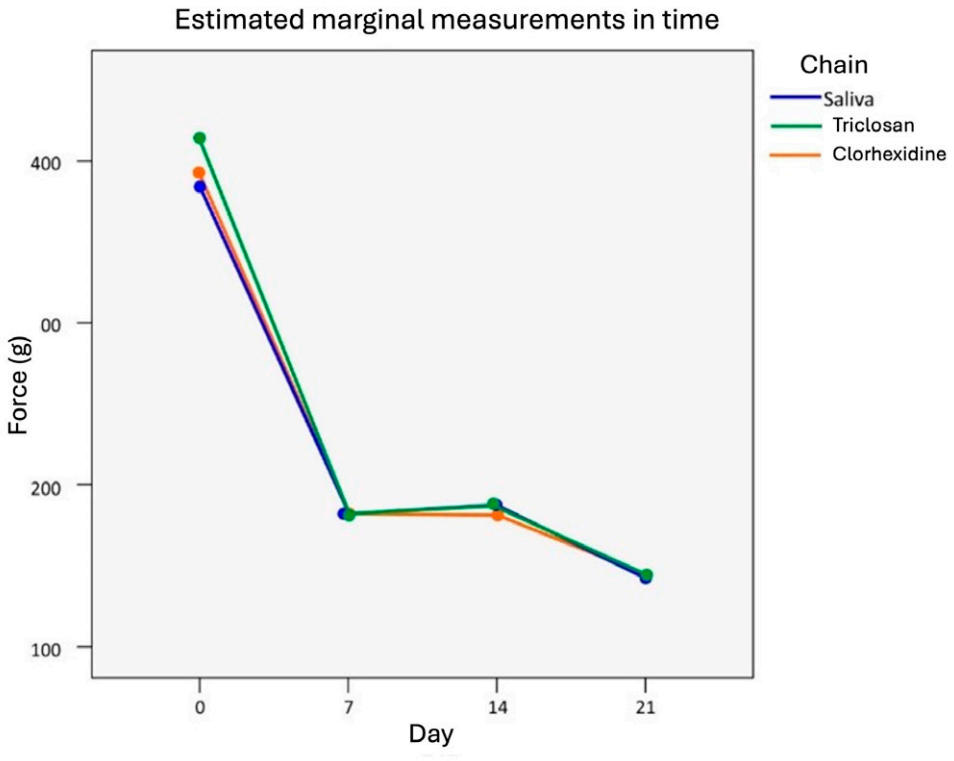
	Treatment		Strength loss in Mega Pascals Mean difference (CI 95 %)	p
Saliva	**Basal measurement[a]**	**7 days [b]**	2.047 (1.996-2.098)	0.000*
		14 days [c]	1.984 (1.907-2.062)	0.000*
		21 days [c]	2.422 (2.372-2.472)	0.000*
	7 days	**14 days [c]**	-0.063 (-0.113- -0.012)	0.009*
		21 days [c]	0.375 (0.344-0.407)	0.000*
	14 days	**21 days [c]**	0.438 (0.381-0.494)	0.000*
Triclosan	**Basal measurement[a]**	**7 days [b]**	2.311 (1.745- 2.876)	0.000*
		14 days [c]	2.280 (1.708- 2.851)	0.000*
		21 days [c]	2.691 (2.119- 3.262)	0.000*
	7 days [b]	**14 days [c]**	-0.031 (-0.068- 0.006)	0.153
		21 days [c]	0.380 (0.341- 0.420)	0.000*
	14 days [c]	**21 days [c]**	0.411 (0.372- 0.451)	0.000*

Table 2. Continued

	Treatment		Strength loss in Mega Pascals Mean difference (CI 95 %)	p
Clorhexidine	**Basal measurement[a]**	**7 days[b]**	2.118 (2.088- 2.147)	0.000*
		14 days[c]	2.116 (2.09- 2.142)	0.000*
		21 days[c]	2.496 (2.465- 2.527)	0.000*
	7 days[b]	**14 days[c]**	-0.001 (-0.03- 0.027)	0.923
		21 days[c]	0.378 (0.347- 0.409)	0.000*
	14 days[c]	**21 days[c]**	0.380 (0.349- 0.41)	0.000*

Repeated measures ANOVA test, *significance p<0.05

Graph 1 shows that the trend of loss of strength for the three solutions is very evident between the baseline measurement and 7 days; however, for the measurement from 7 to 14 days there was a slight increase in strength in all three groups, but for the 21 days measurement there was a decrease in strength. Likewise, in the elastic distal ligature group, it was found that there was no difference in the loss of strength when comparing the three solutions (Table 3). Additionally, when evaluating the loss of strength over time when immersed in saliva, chlorhexidine, and triclosan, a statistically significant decrease trend was observed. For the ligatures immersed in saliva and chlorhexidine, we found differences between the basal measurement and at 7, 14, and 21 days, for triclosan all the comparisons were statistically significant, except between 14 and 21 days (Table 4).



Graph 1. Estimated marginal measurements in time.

Table 3.
Effect of three solutions on the loss of strength of the elastic distal ligature.

Solutions		Strength loss in Mega Pascals Mean difference (CI 95 %)	p
Saliva [a]	**Triclosan [b]**	-0.050089 (-0.150871- 0.050693)	0.685
	Clorhexidine [c]	0.008879 (-0.091903- 0.109661)	1.000
Triclosan [b]	**Saliva [a]**	0.050089 (-0.050693- 0.150871)	0.685
	Clorhexidine [c]	0.058968 (-0.041813- 0.15975)	0.470
Clorhexidine [c]	**Saliva [a]**	-0.008879 (-0.109661- 0.091903)	1.000
	Triclosan [b]	-0.058968 (-0.15975- 0.041813)	0.470

ANOVA test, significance p<0.05

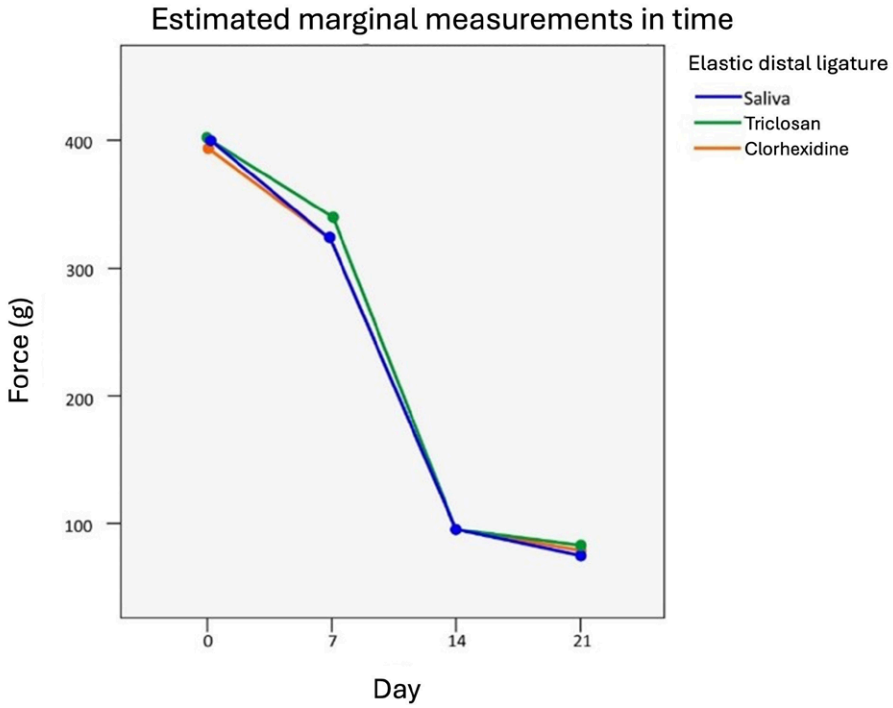
Table 4.
Comparison of the effect of three solutions at four time measurements on the loss of strength of the elastic distal ligature

	Group		Strength loss in Mega Pascals Mean difference (CI 95 %)	p
Saliva	**Basal measurement**	**7 days [b]**	0.779 (0.647- 0.911)	0.000*
		14 days [c]	3.050 (2.885- 3.214)	0.000*
		21 days [c]	3.273 (3.18- 3.366)	0.000*
	7 days	**14 days [c]**	2.270 (2.139- 2.401)	0.000*
		21 days [c]	2.494 (2.374- 2.614)	0.000*
	14 days	**21 days [c]**	0.223 (0.111- 0.336)	0.000*
Triclosan	**Basal measurement**	**7 days [b]**	0.584 (0.387- 0.781)	0.000*
		14 days [c]	3.037 (2.85- 3.224)	0.000*
		21 days [c]	3.197 (3.045- 3.349)	0.000*
	7 days [b]	**14 days [c]**	2.453 (2.234- 2.672)	0.000*
		21 days [c]	2.613 (2.379- 2.847)	0.000*
	14 days [c]	**21 days [c]**	0.16 (-0.011- 0.331)	0.079
Clorhexidine	**Basal measurement [a]**	**7 days [b]**	0.690* (0.531- 0.849)	0.000*
		14 days [c]	2.970* (2.794- 3.145)	0.000*
		21 days [c]	3.160* (3.05- 3.271)	0.000*
	7 days [b]	**14 days [c]**	2.279* (2.08- 2.479)	0.000*
		21 days [c]	2.470* (2.287- 2.653)	0.000*
	14 days [c]	**21 days [c]**	0.191* (0.002- 0.38)	0.047*

Repeated measures ANOVA test, *significance p<0.05

Graph 2 shows that the tendency of the loss of strength is constant, regardless of the solution; however, the greatest loss was found between the measurement at 7 and 14 days for the three solutions, and very attenuated for the measurement from 14 to 21 days. In addition, the effect of the solutions was compared over time for both groups. For saliva the loss of force between the chain and the distal ligature in the four measurements showed statistically

significant differences, with the loss of force in the chain being greater for the first two measurements and reversing in the following two. For triclosan and chlorhexidine all the comparisons were significant except for the basal measurement. Likewise, we observed the same trend of loss of force between the groups as that shown in saliva (Table 5).



Graph 2. Estimated marginal measurements in time.

Table 5.
Comparison of means of the chain technique and elastic distal ligature in different environments and time.

	Strength loss in Mega Pascals							
	(measurement 1)		(measurement 2)		(measurement 3)		(measurement 4)	
	Mean (Confidence interval - 95%)	p	Mean (CI- 95%)	p	Mean (CI- 95%)	p	Mean (CI- 95%)	p
Saliva								
Chain	3.86(3.83- 3.89)	<0.001	1.81(1.78-1.84)	<.001	1.87(1.82-1.92)	<.001	1.43(1.41-1.46)	<0.001
Distal ligature	4.01(3.95-4.07)		3.23(3.11-3.35)		0.96(.83-1.10)		0.742(0.678-0.806)	
Triclosan								
Chain	4.13(3.73-4.54)	0.4818	1.82(1.80-1.84)	<.001	1.85(1.83-1.88)	<.001	1.44(1.43-1.46)	<0.001
Distal ligature	3.99(3.92-4.05)		3.4(3.26-3.55)		0.957(.833-1.08)		.797(.718-.877)	
Clorhexidine								
Chain	3.93(3.91-3.95)	0.8959	1.81(1.78-1.84)	<.001	1.81(1.78-1.84)	<.001	1.43(1.41-1.45)	0.971
Distal ligature	3.93(3.86-4.00)		3.24(3.12-3.36)		0.966(.850-1.08)		0.775(0.723-0.828)	<0.001

Student's t-test, significance p< 0.05

DISCUSSION

Many studies have been conducted on elastomeric chains; however, there are very few studies on elastic distal ligatures. Therefore, it is important to know the factors that have an impact on the degradation of the initial strength such as stretch length, time to remain deformed, fabrication method, contact liquids, and pigments, to choose the most efficient material. The results of this study show that elastomeric chains are not able to maintain constant forces for 21 days; the same was reported in the studies performed by Baty *et al*.[10]; Hershey and Reynolds[5], and Wong[6]. After 21 days of stretching the chains, the initial remaining force was 37%, in contrast to what Weissheimer *et al*.[13] reported in their study where the remaining force was 40-45%.

The degradation pattern of the strength of the chains suffers the greatest loss during the first few days, then remains more constant, and at the end of 21 days the remaining strength is too little to be able to perform dental movements; the same was obtained in studies by Mirhashemi *et al*.[14], Lu *et al*.[15], da Silva *et al*.[16], Santos *et al*.[17], Morales-Pulachet *et al*.[18], and Balhoff *et al*.[19].

In this study elastic chains made by stamping presented a better mechanical behavior, obtaining results similar to those presented by Hershey and Reynolds[5], in comparison with the elastic modules used in distal ligatures which are elaborated by injection. For this study, the length (25.6mm) to which the samples were put through was obtained from the average measurement of patients under orthodontic treatment who were ready to begin the space closure phase; this measurement is similar to that used in studies by Nattrass *et al*. [20] and Freeman *et al*.[21]; as opposed to that used by other authors based on stretching the elastic chain samples to double their original size[14,22] or an arbitrary measurement[13,15,18,23]. Morales-Pulachet *et al*. described that on day 21, a degradation of strength of 80-82%[18] happened. These results are different from the ones obtained in this study where a 63% degradation of strength was found. The difference may lie in the fact that the commercial brand of the chain was different.

The elastomeric chains that were immersed in 0.12% chlorhexidine did not show significant changes compared to the other groups; however, in the study by Omidkhoda *et al*., differences were identified; the result of this study may be attributed to the fact that chlorhexidine had a higher concentration, *i.e.*, of 0.20%[24]. As already mentioned, there are few studies in which mechanical tests are performed on the elastic distal ligature; however, the study by Mohammadi and Mahmoodi[25] shows a behavior similar to that of the elastomeric chains, where the greatest loss of strength occurs during the first week and not until the second week as obtained in this study. However, in that study, the elastomeric modules were pre-stretched.

Ren *et al*.[26] describe that there is insufficient clinical evidence to establish an ideal biological force for dental movement. However, a force of between 150-350g[9] has been established in the studies carried out in humans. In elastic distal ligature, values above 350g are maintained during the first seven days, which could be related to root resorption and greater discomfort perceived by the patient, as indicated by Halimi *et al*.[27]; after the seventh day the force decreases rapidly so that during the third week of the use of elastic distal ligature the remaining values of force are no longer sufficient for dental movement.

CONCLUSIONS

- Time is the most important factor in the loss of strength of elastomers.
- Elastomeric chains have a large loss of strength in the first 7 days, however, thereafter it remains constant up to 21 days, with biological forces.

- The elastic distal ligature suffers the greatest loss of strength up to 14 days. Thereafter its strength is no longer functional for tooth movement.
- There are no changes in the mechanical behavior of the chain or distal ligature if the patient is under any oral antiseptic therapy such as 0.12% chlorhexidine or triclosan.

BIBLIOGRAPHIC REFERENCES

1. Barsoum HA, ElSayed HS, El Sharaby FA, Palomo JM, Mostafa YA. Comprehensive comparison of canine retraction using NiTi closed coil springs vs elastomeric chains: A split-mouth randomized controlled trial. *Angle Orthod*. 2021; 91(4): 441-448. DOI: 10.2319/110620-916.1
2. Mousavi SM, Mahboobi S, Rakhshan V. Effects of different stretching extents, morphologies, and brands on initial force and force decay of orthodontic elastomeric chains: An in vitro study. *Dent Res J (Isfahan)*. 2020;17(5):326-337. Disponible en: https://journals.lww.com/derj/fulltext/2020/17050/effects_of_different_stretching_extents,.2.aspx
3. Evans KS, Wood CM, Moffitt AH, Colgan JA, Holman JK, Marshall SD, *et al*. Sixteen-week analysis of unaltered elastomeric chain relating in-vitro force degradation with in-vivo extraction space tooth movement. *Am J Orthod Dentofacial Orthop*. 2017; 151(4): 727-734. DOI: 10.1016/j.ajodo.2016.10.020
4. Andreasen GF, Bishara S. Comparison of Alastik chains with elastics involved with intra-arch molar to molar forces. *Angle Orthod*. 1970; 40(3): 151-158. Disponible en: https://meridian.allenpress.com/angle-orthodontist/article-pdf/40/3/151/1369455/0003-3219(1970)040_0151_coacwe_2_0_co_2.pdf
5. Hershey HG, Reynolds WG. The plastic module as an orthodontic tooth-moving mechanism. *Am J Orthod*. 1975; 67(5): 554-562. DOI: 10.1016/0002-9416(75)90300-0
6. Wong AK. Orthodontic elastic materials. *Angle Orthod*. 1976; 46(2): 196-205. Disponible en: https://meridian.allenpress.com/angle-orthodontist/article-pdf/1369353/0003-3219(1976)046_0196_oem_2_0_co_2.pdf
7. Kovatch JS, Lautenschlager EP, Apfel DA, Keller JC. Load-extension-time behavior of orthodontic Alastiks. *J Dent Res*. 1976; 55(5): 783-786. DOI: 10.1177/00220345760550051201
8. Ash JL, Nikolai RJ. Relaxation of orthodontic elastomeric chains and modules in vitro and in vivo. *J Dent Res*. 1978; 57(5-6): 685-690. DOI: 10.1177/00220345780570050301
9. Mohammed H, Rizk MZ, Wafaie K, Almuzian M. Effectiveness of nickel-titanium springs vs elastomeric chains in orthodontic space closure: A systematic review and meta-analysis. *Orthod Craniofac Res*. 2018; 21(1): 12-19. DOI: 10.1111/ocr.12210
10. Baty DL, Storie DJ, von Fraunhofer JA. Synthetic elastomeric chains: a literature review. *Am J Orthod Dentofacial Orthop*. 1994; 105(6): 536-542. DOI: 10.1016/S0889-5406(94)70137-7
11. Von Fraunhofer JA, Coffelt MT, Orbell GM. The effects of artificial saliva and topical fluoride treatments on the degradation of the elastic properties of orthodontic chains. *Angle Orthod*.1992; 62(4): 265-274. Disponible en: https://meridian.allenpress.com/angle-orthodontist/article-pdf/1372554/0003-3219(1992)062_0265_teoasa_2_0_co_2.pdf
12. McLaughlin RP, Bennett JC, Trevisi HJ. *Mecánica Sistematizada del Tratamiento Ortodóncico*. Madrid: Mosby; 2002.
13. Weissheimer A, Locks A, de Menezes LM, Borgatto AF, Derech CDA. In vitro evaluation of force degradation of elastomeric chains used in orthodontics. *Dental Press J Orthod*. 2013; 18(1): 55-62. DOI: 10.1590/s2176-94512013000100014

14. Mirhashemi AH, Saffarshahroudi A, Sodagar A, Atai M. Force-degradation pattern of six different orthodontic elastomeric chains. *J Dent (Tehran)*. 2012; 9(4): 204–15.
15. 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): 373-377. DOI: 10.1016/S0889-5406(05)81336-8
16. Da Silva D, Kochenborger C, Marchioro EM. Force degradation in orthodontic elastic chains. *Rev odonto ciênc*. 2009; 24(3): 274-278. https://revistaseletronicas.pucrs.br/index.php/fo/article/view/4408/4511
17. Santos ACS, Tortamano A, Naccarato SRF, Dominguez-Rodriguez GC, Vigorito JW. An in vitro comparison of the force decay generated by different commercially available elastomeric chains and NiTi closed coil springs. *Braz Oral Res*. 2007; 21(1): 51-57. DOI: 10.1590/s1806-83242007000100009
18. Morales-Pulachet EC, Lavado-Torres A, Quea-Cahuana E. Degradación de fuerzas en cadenas elastoméricas de dos marcas diferentes. Estudio in vitro. *Kiru*. 2014;11(2):110-114. Disponible en: https://portalrevistas.aulavirtualusmp.pe/index.php/Rev-Kiru0/article/view/125/104
19. Balhoff DA, Shuldberg M, Hagan JL, Ballard RW, Armbruster PC. Force decay of elastomeric chains - a mechanical design and product comparison study. *J Orthod*. 2011; 38(1): 40-47. DOI: 10.1179/14653121141227
20. Nattrass C, Ireland AJ, Sherriff M. The effect of environmental factors on elastomeric chain and nickel titanium coil springs. *Eur J Orthod*. 1998; 20(2): 169-176. DOI: 10.1093/ejo/20.2.169
21. Freeman DH, Johnston WM, Brantley WA, Firestone AR. Idealized force decay of orthodontic elastomeric chains follows Nutting equation. Med Devices Sens. 2021;4(1):e10145. DOI: 10.1002/mds3.10145
22. Eliades T, Eliades G, Silikas N, Watts DC. Tensile properties of orthodontic elastomeric chains. *Eur J Orthod*. 2004; 26(2): 157-162. DOI: 10.1093/ejo/26.2.157
23. Sánchez Herrera ML, Katagiri M, Álvarez Gayoso C. Estudio in vitro del deterioro de las propiedades elásticas de las cadenas elastoméricas. Rev Odont Mex. 2006; 10(2): 79-82. DOI: 10.22201/fo.1870199xp.2006.10.2.15906
24. Omidkhoda M, Rashed R, Khodarahmi N. Evaluation of the effects of three different mouthwashes on the force decay of orthodontic chains. *Dent Res J (Isfahan)*. 2015;12(4):348-352. DOI: 10.4103/1735-3327.161453
25. Mohammadi A, Mahmoodi F. Evaluation of force degradation pattern of elastomeric ligatures and elastomeric separators in active tieback state. *J Dent Res Dent Clin Dent Prospects*. 2015; 9(4): 254-260. DOI: 10.15171/joddd.2015.045
26. Ren Y, Maltha JC, Kuijpers-Jagtman AM. Optimum force magnitude for orthodontic tooth movement: a systematic literature review. *Angle Orthod*. 2003; 73(1): 86-92. Disponible en: https://meridian.allenpress.com/angle-orthodontist/article-pdf/1374366/0003-3219(2003)073_0086_ofmfot_2_0_co_2.pdf
27. Halimi A, Benyahia H, Doukkali A, Azeroual M-F, Zaoui F. A systematic review of force decay in orthodontic elastomeric power chains. *Int Orthod*. 2012; 10(3): 223-240. DOI: 10.1016/j.ortho.2012.06.013