Thermocycling effect on chain elastic force degradation

O efeito da termociclagem na degradação de força de elásticos em cadeia

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ABSTRACT
The objective of this study was to evaluate the effect of temperature variation on the degradation of chain forces of elastics of different brands. To compose the experimental (G) groups, 100 segments of elastics were made, being 20 of each brand: G1 - American Orthodontics; G2 - TP Orthodontics; G3 - 3M Unitek/ESPE; G4 – GAC; and, G5 - Rocky

Mountain (RM). Half of the elastics (n=10) were submitted to thermocycling, and the other half were stored in distilled water at 37ºC. All samples were submitted to force degradation analysis in the Instron universal testing machine, the first reading being performed after the specimens were made and repeated after a period of 28 days. During this period, the elastics remained stretched on acrylic plates. The data were submitted to mixed models for repeated measurements and the Data were submitted to Analysis of Variance 2 factors and the Tukey test (α = 0.05). Group G2 showed significantly higher mean strength in initial and final times, with and without thermocycling. Group G1 presented significantly higher mean strength in relation to groups G3, G4 and G5 at initial time ($p<0.05$). In the final time, G1 showed a significantly lower force than G5 without cycling and lower than G4 and G5 with cycling. There was no significant difference between the groups with and without cycling, with significant decrease of force in all brands. When analyzing the degradation of force in the initial and final times, it is observed greater degradation in the groups submitted to thermocycling, and G1 presented greater degradation of force, while groups G4 and G5 presented less degradation. It is concluded that the variation of temperature increased the degradation of the elastics in the chain for all the analyzed brands. The American Orthodontics elastic showed the highest degradation of strength, while the GAC and RM elastics showed the lowest degradation.

Keywords: Orthodontics, elastic chain, Force Degradation.

RESUMO
O objetivo deste estudo foi avaliar o efeito da variação da temperatura na degradação das forças da cadeia de elásticos de diferentes marcas. Para compor os grupos experimentais (G), foram confeccionados 100 segmentos de elásticos, sendo 20 de cada marca: G1 - American Orthodontics; G2 - TP Ortodôntica; G3 - 3M Unitek / ESPE; G4 - GAC; e, G5 - Rocky Mountain (RM). Metade dos elásticos (n = 10) foi submetida à termociclagem e a outra metade armazenada em água destilada a 37ºC. Todas as amostras foram submetidas à análise de degradação de força na máquina de ensaio universal Instron, sendo a primeira leitura realizada após a confecção dos corpos-de-prova e repetida após um período de 28 dias. Nesse período, os elásticos permaneceram esticados em placas de acrílico. Os dados foram submetidos a modelos mistos para medidas repetidas e os dados foram submetidos à Análise de Variância 2 fatores e ao teste de Tukey (α = 0,05). O Grupo G2 apresentou resistência média significativamente maior nos tempos inicial e final, com e sem termociclagem. O grupo G1 apresentou média de força significativamente maior em relação aos grupos G3, G4 e G5 no momento inicial ($p <0,05$). No tempo final, G1 apresentou força significativamente menor que G5 sem pedalar e menor que G4 e G5 com pedalada. Não houve diferença significativa entre os grupos com e sem ciclismo, com diminuição significativa da força em todas as marcas. Ao analisar a degradação da força nos tempos inicial e final, observa-se maior degradação nos grupos submetidos à termociclagem, sendo que G1 apresentou maior degradação da força, enquanto os grupos G4 e G5 apresentaram menor degradação. Conclui-se que a variação da temperatura aumentou a degradação dos elásticos na cadeia para todas as marcas analisadas. Os elásticos da American Orthodontics apresentaram a maior degradação da resistência, enquanto os elásticos GAC e RM apresentaram a menor degradação.

Palavras-chave: Ortodontia, cadeia elástica, Degradação de forças.

1 INTRODUCTION

Synthetic elastomeric chains were introduced in dentistry in the 1960s and became an integral part of orthodontic practices [1]. Among the main advantages of this material are ease of use, low cost, low risk of trauma to intraoral tissues, minimal need for patient cooperation and wide variety of colors and transparency. The disadvantages are inconsistency of strength levels over time, absorption of oral fluids, color change, loss of strength leading to gradual loss of effectiveness and permanent deformation [2,3].

It is a consensus that elastomeric chains do not exert a continuous force. Different factors such as temperature variation, pH changes, salivary enzymes, elastic pre-stretching, amount of force applied at the time of elastic insertion and masticatory forces have been related to behavioral changes of elastomeric chains [1,4,5] Studies in the literature have shown that there has been a decline in force soon after its application, and a gradual reduction from the first 24 hours and over the following weeks [6,7,8,9,10,11]. Another study showed that when exposed in the oral cavity or *in vitro* with moisture, these elastics showed loss of residual strength when compared to the elastics kept in dry environments [12].

Therefore, and being susceptible to the constant variations that the oral environment can suffer, such as the great variations of temperature induced by the ingestion of hot or cold beverages, it can take some time to return to the initial temperature. Thus, a change in strength may occur due to this temperature oscillation in the oral environment, and in some cases may influence the clinical evolution of treatments according to the specific diet or habits of the patient [13, 14]. On the other hand, this force variation is not only related to intraoral conditions, but also to differences between commercial brands. Among the existing brands in the market, it is possible to notice clinically that there is a difference in relation to the decline in strength and efficiency of this material.

Thus, the analysis of the effect of temperature variation on the degradation of elastomeric chain forces at the time it was applied up to four weeks after this application, in order to achieve the force levels with the least possible variation, aims to reproduce the simulation of the clinical use of these materials and optimization of orthodontic treatment. Thus, the objective of this study was to evaluate the force degradation of different elastic chains submitted or not to temperature variation after 28 days. Two hypotheses were tested: 1) The 28-day storage period and thermocycling will not affect the force reduction of the five elastic chain marks; and, 2) No significant difference in force reduction will be observed between the five elastic chain marks.

2 MATERIALS AND METHOD

2.1 EXPERIMENTAL DESIGN

One hundred elastic segments were randomly divided into ten groups (n=10), according to Chart 1.

Chart 1 - Experimental groups of the five trademarks, with and without thermocycling

Groups	Elastics	Aging
G1	American Orthodontics (AO)	without thermocycling
G2	American Orthodontics (AO)	with thermocycling
G3	TP Orthodontics (TP)	without thermocycling
G4	TP Orthodontics (TP)	with thermocycling
G5	3M Unitek/ESPE (3M)	without thermocycling
G6	3M Unitek/ESPE (3M)	with thermocycling
G7	GAC	without thermocycling
G8	GAC	with thermocycling
G9	Rocky Mountain (RM)	without thermocycling
G10	Rocky Mountain (RM)	with thermocycling

Force degradation was obtained with the help of the Instron universal testing machine (model 4411 Canton, USA), after the specimens were made and after a period of 28 days. Half of the specimens of each trademark were thermocycled on the MSCT 3 machine (Marnucci ME, São Carlos, Brasil).

2.2 PREPARATION OF SPECIMENS

Elastomeric chains of mean size of five trademarks: American Orthodontics (Sheboygan, Wis, USA), TP Orthodontics (La Porte, Ind, USA), 3M Unitek/ESPE (St. Paul, Minn, USA), GAC (Bohemia, NY, USA) and Rocky Mountain (Denver, Colo, USA), were selected in the color gray, purchased sealed and on expiration date. Ten segments of elastomeric chains of the same brand were fixed on 10 transparent acrylic plates (1 for each experimental group) of 11 cm long, 4 cm wide and 1 cm thick (Vitória, Espírito Santo, Brazil) (Kochenborger, 2011) with pins fixed at a distance of 15 mm between them (Javanmardi and Salehi, 2016). The elastics were pre-stretched 3 times, quickly and sequentially, using a Mitutoyo digital pachymeter (Kanagawa, Takatsu-ku, Japan), in 50% of their length before being adapted to the plates [15].

2.3 THERMOCYCLING

The samples of groups 2, 4, 6, 8 and 10 were submitted to 500 thermal cycles (ISO TR 11450) in the thermal cycler machine (MSCT 3, Marnucci ME, São Carlos, SP, Brazil) with deionized water between 5ºC and 55ºC (for 30 seconds at each temperature) with transfer time between baths of 6 seconds [16]. After this period, the samples were again immersed in distilled water at 37º and kept in an oven.

2.4 FORCE READING

The force measurement of the elastomeric segments of all experimental groups was performed shortly after the test specimens were made (T0) and repeated after a 28-day interval (T1) on the Instron universal testing machine (Instron Corp, model 4411, Canton, USA) at a speed of 5mm/minute. The force measurements were obtained by a single examiner. Each chain was stretched by 3 mm. The magnitudes of the elastic's extension force (when stretched to a distance of 15 mm) were recorded immediately after being removed. The traction readings were recorded in grams of force (gf) lasting 1 minute for each elastic chain.

2.5 STATISTICAL ANALYSIS

After exploratory analysis, the force data were submitted to mixed model methodology for repeated measurements in time considering the manufacturing, cycling and time factors, as well as the interactions between them. Multiple comparisons were performed by the Tukey-Kramer test. Force degradation in relation to initial time was submitted to analysis of variance (ANOVA) in factor scheme 2 x 5 (thermocycling x manufacturer). Multiple comparisons were performed by the Tukey-Kramer test ($\alpha = 0.05$). The analyses were performed in the SAS program (SAS Institute Inc., Cary, NC, USA, Release 9.2, 2010).

3 RESULTS

Mean force values are shown in table 1. The TP elastic showed mean force significantly higher than other manufacturers, with and without thermocycling, in the initial and final times ($p<0.05$). The American Orthodontics elastic showed mean force (256.48 ± 11.80 gf) significantly higher than the 3M elastic (189.90 ± 7.63), GAC (174.03 ± 5.84) and RM (174.59 ± 4.83) in the initial time ($p<0.05$). Similar results were obtained in the initial time with thermocycling. In the final time, American Orthodontics (120.06 ± 24.04) showed significantly lower strength than RM in groups without cycling and then GAC and Rocky Mountain Orthodontics (RM) in groups with cycling ($p<0.05$). The strength in the initial period was statistically superior to the final ($p<0.05$) for all brands, with and without thermocycling ($p<0.05$). There was no significant difference in strength between groups with and without thermocycling ($p>0.05$).

Regarding the elastics of American Orthodontics, the mean percentage of strength loss (%) was higher than the others ($p<0.05$), without or with thermocycling, with a percentage of 53.1% and 62.8%, respectively. The GAC and Rocky Mountain Orthodontics (RM) elastics presented the lowest degradation (18.7%; 20.4%; 13.4%; and, 15.3% without and with cycling, respectively, for GAC and RM) ($p<0.05$).

Table 1. Mean of force values (gf) and standard deviation for orthodontic elastic chain in different storage periods, with or without thermocycling.

Branc	Thermocycling			
	Without cycling		With cycling	
	Initial	Final	Initial	Final
AO	256,48 (11,80) Ba	120,16 (24,04) CDb	255,61 (10,54) Ba	95,03 (20,21) Cb
TP	388,54 (17,91) Aa	251,24 (28,78) Ab	380,88 (18,23) Aa	252,11 (17,57) Ab
3M	189,90 (7,63) Ca	111,49 (10,10) Db	194,54 (5,05) Ca	108,32 (11,84) Cb
GAC	174,03 (5,84) Ca	141,48 (13,22) BCb	176,13 (5,84) Da	140,10 (8,69) Bb
RM	174,59 (4,83) Ca	151,13 (11,45) Bb	174,86 (8,73) Da	148,04 (14,22) Bb

There was no significant difference between the groups with and without cycling ($p>0.05$). Means followed by different letters (upper case vertical and lower case horizontal comparing times within each level of thermocycling) differ ($p<0.05$). p(manufacturer)<0.0001; p(cycling)=0.1165; p(time)<0.0001; p (manufacturer x cycling) =0.2302; p (manufacturer x time) <0.0001; p (cycling x time) =0.1205; p (manufacturer x cycling x time) =0.1235.

4 DISCUSSION

Elastomeric chains are widely used in orthodontics to facilitate teeth movement, mainly due to the transmission of force to the teeth. However, their behavior regarding maintenance and predictability of force exerted may not be considered ideal, since the force generated decreases gradually and in a heterogeneous manner over time [17, 18]. Several studies have analyzed the behavior of these materials in relation to force degradation and which factors influence this behavior [1,10,11,12,15,19,20,21,22,23,24,25,26]. The method used in the present study tried to simulate the use of these elastic chains in the laboratory. Immersion in a humid environment is widely used as the objective of analyzing orthodontic elastics. However, they may be suitable for a short testing period [12].

The amount of force required for tooth movement varies according to some factors such as: root surface, bone insertion and required movement. Intermittent forces between 70 and 100 grams are already able to produce a hyalinization zone on the pressure side for tooth movement [27]. For canine retraction the recommended force varies between 200 and 300 grams [21,27,28,29].

Usually, elastic chains are evaluated for a period of 28 days. This is the time normally used by orthodontists to change these elastics [30,31,32,33]. In the present study, the strength was evaluated immediately after 28 days and after thermocycling. thermocycling was used to try to simulate what can happen daily with the patient during the ingestion of hot or cold liquids or food.

The first hypothesis suggested in the study, which stated that the 28-day storage period and thermocycling would not affect the reduction of the strength of the five brands of elastics in chain, was partially accepted. The results showed a significant decrease in the amount of force obtained after the 28-day storage period in relation to the immediate one for AO, T, 3M, GAC and RM elastic chains, without or with thermocycling, with a percentage of 53.1%, 35.4%, 41.3%, 18.7% and 13.4%, (without cycling) and 62.8%, 33.8%, 44.3%, 20.4% and 15.3% (with cycling), respectively. However, no statistical difference was observed when the elastic chains were submitted to thermocycling.

The results found in the present study do not corroborate those obtained in previous studies, which showed initial strength loss between 50% and 70% on the first day of use, with the elastic chain having approximately 28% to 40% of its initial strength on the third or fourth week of use [34,35,36,37]. In this study, only the AO elastic chain had approximately 46.8% (without cycling) and 37.2% (with cycling) of its initial strength after the fourth week of use (28 days). For the other elastic chains, it remained approximately 58.7% to 86.6% (without cycling) and 55.6% to 84.7% (with cycling) of its initial strength after the fourth week of use. The oral environment is characterized by constant thermal changes, which can influence the physical and mechanical properties of materials.

In this sense, the thermocycling used in this study is an *in vitro* process that tries to reproduce these thermal changes that constantly occur in the oral cavity during feeding, liquid intake and breathing [16]. Some studies have shown that from the initial force in the 24 hours after the cycling test, there was a reduction in force of 15.6% for latex elastics and 8.2% for latex elastics [37,38]. The literature showed a reduction in the strength of elastics up to the 24-hour storage time [39]. Another study has shown that the reduction in elasticity, associated with almost constant forces, may suggest that elastomeric elastic chains begin to become brittle, losing their elasticity rapidly [36]. It is still possible to infer that during orthodontic treatment, significant force degradation occurs in elastics.

Thus, it is noted that the literature does not establish a consensus on the value of degradation, however, 10% has been the value used for difference. This value can be clinically significant for the elastomeric chains during orthodontic treatment and was measured only after 24 hours [37]. In the present study, after the 28-day storage period and thermocycling, the force reduction ranged from 15% to 63%.

When the elastic chain factor was analyzed, a large variation between the initial forces was observed (174.03 to 388.54 gf), besides the significant reduction between the marks after 28 days (with or without thermocycling), corroborating the findings of other studies [1, 39]. These results indicate that the second hypothesis was rejected. The TP showed mean force significantly higher than other manufacturers, with and without thermocycling, in the initial and final times ($p<0.05$). This may have occurred since for the standard distance of 15 mm, a smaller number of links (3 links) was required for the TP elastic, when compared to the amount of links of the other brands (4 links), necessary to generate force close to each other and to the forces normally used in clinical management. Moreover, TP elastomeric chains presented longer interlinked bridges than the other brands studied, so the segments of all brands are closer in length and strength. Thermocycling had no effect on the significant loss of strength of the chain elastics in relation to the samples that were not submitted to cycling. A possible explanation is that the difference in diameter of the elastomeric chains may have influenced the force values obtained between the different brands [39]. Associated to this, the different polymeric chains, evaluated in the present study, were less susceptible to the influence of water sorption during cycling [40].

Thus, knowledge of the changes in the mechanical properties of chain elastics, when stretched, stored and submitted to thermocycling, becomes necessary for the correct use and obtaining satisfactory clinical results. However, clinicians should be careful with the results obtained in this study, so that it is not used to claim that one brand is superior to another. In addition, thermocycling has not been significant in the degradation of elastomeric chain strength. Therefore, additional *in vitro* and *in vivo* studies should be conducted using different time intervals after immersion in water, associated with mechanical brushing and thermocycling.

6 CONCLUSION

(1) The 28-day storage significantly influenced the force degradation for all chain elastics. As for thermocycling, it did not influence force degradation;

(2) The American Orthodontics chain elastic presented the highest force degradation, while GAC and MR presented the lowest;

(3) The TP chain elastic presented mean force significantly higher than other manufacturers, with and without thermocycling, in the initial and final times; and,

(4) The clinician, when using chain elastics, should be aware that these materials have limitations and that there are differences between manufacturers, because these differences directly imply in the evolution of their treatments. Knowing the clinical behavior of the various types of elastics available on the market makes it easier to choose the materials and behaviors to be used in their patients.

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