Brazilian Dental Science
unesp
UNIVERSIDADE ESTADUAL PAULISTA "JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
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ORIGINAL ARTICLE DOI: https://doi.org/10.14295/bds.2022.e2612

Force decay and discoloration of thermoplastic and thermoset orthodontic elastomeric chains

Diminuição de força e descoloração de elásticos corrente termoplásticos e termofixos

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ABSTRACT

Objective: Elastomeric chains are commonly used to apply force for orthodontic dental movements. However, force decay and discoloration are two important weak points of these materials. The present study intended to compare the force decay and color stability of different types of elastomeric chains. **Material and Methods**: This in vitro study evaluated 6 groups of elastomeric chains, including thermoplastic (TP) and thermoset (TS) chains made by the companies American Orthodontics (AO), Ormco (OR), and G&H Orthodontics (GH). The elastomeric chain forces were measured at the baseline, following 1 hour, 1 day, 1, 2, 3, 4, 5, and 6 weeks of stretching. The elongation required for the chains to exert a force of 250 g was calculated. ΔE of each group was calculated by a spectrophotometer following immersion in black tea solution for 6 days. Data were analyzed using the SPSS 22 software and the statistical methods of repeated measures analysis of variance and two-way analysis of variance ($P<0.05$). **Results**: The force decay of the TS chains were significantly lower than the TP chains in the 6-week study duration ($P<0.05$), and the lowest and highest force decay was observed in the products by AO and GH, respectively. The highest force degradation occurred during the first week in all groups. The elongation rate needed for the TS chains was significantly higher than the TP chains ($P<0.05$), and the highest elongation rate was observed in the products by OR. TS chains showed significantly higher color stability than TP chains, and products by OR and GH had better color stability than the products by AO. **Conclusion**: The present study showed that TS chains were superior to TP chains in force decay and color stability in all the brands studied.

KEYWORDS

Color; Elastomeric; Force decay; Thermoplastic; Thermoset.

RESUMO

Objetivo: Elásticos corrente são comumente utilizados para aplicar forças para a movimentação ortodôntica. Porém, a diminuição de força e descoloração são duas importantes fraquezas desses materiais. O presente estudo tem o objetivo de comparar a diminuição de força e estabilidade de cor de diferentes tipos de elásticos corrente. **Material e Métodos:** Este estudo in vitro avaliou 6 grupos de elásticos corrente, incluindo termoplástico (TP) e termofixo (TS) produzidos pelas empresas American Orthodontics (AO), Ormco (OR) e G&H Orthodontics (GH). A força dos elásticos corrente foram mensuradas no início, após 1 hora, 1 dia, 1, 2, 3, 4, 5 e 6 semanas de alongamento. A força de alongamento necessária para aplicação de 250g foi calculada. O ΔE de cada grupo foi calculado por um espectrofotômetro após a imersão em solução de chá preto por 6 dias. Os dados foram analizados utilizando o programa SPSS 22 e a análise estatística foi realizada por análise de variância e análise de variância dois fatores ($p<0,05$). **Resultados:** A diminuição da força do grupo TS foi significativamente menor que o grupo TP em 6 semanas de estudo ($p<0,05$), e o menor e maior valor de diminuição de força foi observado nos produtos da empresa AO e GH, respectivamente. A maior degradação de força ocorreu durante a primeira semana em todos os grupos. A taxa de alongamento necessária para o grupo TS foi significativamente maior que o grupo TP ($p<0,05$), e a maior taxa de alongamento foi observada nos produtos da empresa OR. Os elásticos TS obtiveram resultados significativamente maiores de estabilidade de cor que os elásticos TP, e os produtos da OR e GH tiveram melhor estabilidade de cor que oa produtos AO. **Conclusão:** O presente estudo demonstrou que os elásticos TS foram superiores aos elásticos TP em diminuição de força e estabilidade de cor em todas as marcas estudadas.

PALAVRAS-CHAVE

Cor; Elastomérico; Diminuição de força; Termoplástico; Termofixo.

INTRODUCTION

Elastomers are materials returning to their original dimensions rapidly following significant deformations. Since the introduction in the 1960s, elastomeric chains have been widely used in orthodontic treatment for space closure, dental retraction and protraction, and rotation correction [1,2].

Orthodontic tooth movement can be performed using different ways. The use of elastomeric chains for dental movements has various advantages, including low cost, ease of use, patient comfort, and color variation. Moreover, the use of these chains is relatively hygienic. However, force degradation over time is one of their most important disadvantages [1,3,4].

It has been shown that the highest force decay occurs in the first 24 hours [5]. Until now, many studies have evaluated the force degradation of elastomeric chains. These studies showed that different manufacturing methods, such as injection molding or die-cut stamping, do not differ significantly in force degradation [1]. Also, there are controversial results on the effects of initial force [6,7], mechanical design [7,8], and prestreching [9,10] on force degradation.

Elastomeric chains are mainly made of polyurethane and can be thermoplastic or thermoset. Thermoplastic materials can be molded at high temperatures and have weak dipole or van der Waals bonds between their polymers, but thermoset materials are irreversibly cured during the manufacturing process and have stronger covalent bonds. An in vitro study reported that thermoplastic chains had higher force degradation than the thermoset chains [7].

Another problem of elastomeric chains is the discoloration over time. Due to the increasing number of adult patients, there is a demand for more aesthetic appliances, and ceramic brackets are an important part of current orthodontic treatments despite several clinical problems. The use of transparent elastomeric chains for tooth movement, in combination with transparent fixed appliances, improves aesthetics [11]. Moreover, elastomeric chains are subject to discoloration by certain foods and beverages while ceramic brackets are stain-resistant. The discoloration of elastomeric chains and ligatures can be assessed by scoring by the observer [12,13] or instruments for color parameter measurements [14,15].

Due to insufficient studies on the effect of material on force degradation and color stability, we intended to compare the force degradation of transparent thermoplastic or thermoset elastomeric chains during a 6-week period. Moreover, the discoloration of thermoplastic and thermoset elastomeric chains was compared following immersion in black tea solution for 6 days.

MATERIALS AND METHODS

Samples

In this laboratory study, elastomeric chains made by three companies of American Orthodontics, G&H Orthodontics, and Ormco were investigated. These brands were selected because they produced both types of elastomeric chains, thermoplastic and thermoset.

6 groups of transparent elastomeric chains were selected from 3 brands and 2 types of material (thermoplastic and thermoset) to investigate the force decay and color stability:

Group AOTP: American Orthodontics Plastic Chains (Short), thermoplastic

Group GHTP: G&H Orthodontics Dyna-Link Elastomeric Chains (Short), thermoplastic

Group ORTP: Ormco Original Power Chains (Open space), thermoplastic

Group AOTS: American Orthodontics Memory Chains (Short), thermoset

Group GHTS: G&H Orthodontics PowerLinx Chains (Short), thermoset

Group ORTS: Ormco Generation II Power Chains (Open space), thermoset

Measurement of force decay

The elastomeric chains cut to 4-unit segments, and 12 samples of each group (a total of 72 samples) were used to investigate the force degradation. The samples were put under stretching using a Universal Testing Machine (H5KS-1417 Hounsfield Test Equipment LTD, England) at a speed of 20 mm/min to reach a 250 g force (20 seconds after elongation).

The chains were then transferred to a holding appliance in the same length. A holding appliance similar to the study by Mohammadi and Mahmoodi [16] was used to maintain the elongation of the elastomeric chains during the study and prevent release and re-stretching during measurements.

The elastomeric chain lengths were measured using a digital caliper in the passive and stretched forms, and the mean elongation rate of each group of chains under the mentioned force was calculated. Each group of elastomeric chains (12 samples) was placed in 6 separate plastic containers containing artificial saliva (Nikceram, Iran) and incubated at 37° C. Ingredients of the artificial saliva were as follows:

$$CaCl_2.2H_2O, KCl, KSCN, KH2PO4, Na_2SO_4.10H_2O, Urea, NH_4Cl, NaCl \quad (1)$$

The force magnitudes were measured in 1 hour, 1 day, 1, 2, 3, 4, 5, and 6 weeks by transferring the chains from the holder to the Universal Testing Machine. Artificial saliva was renewed weekly.

Discoloration measurement

Another 12 samples from each group (72 samples in total) were used to investigate discoloration. The samples were exposed to the same stretching and were placed in a holding appliance. Color parameters for each sample were determined by a spectrophotometer (SpectroShade Micro, MHT, Italy) using a white background. The samples were then incubated for 6 days in black tea solution (1.6 mg/100 ml) at 37 °C, similar to the study by Lima et al. The black tea solution was changed daily [17]. Color parameters were re-measured following 6 days, and the values of color change (ΔE) in the thermoplastic and thermoset groups were determined for all three brands.

Color change (ΔE) of each group was calculated by the following formula:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (2)$$

Statistical analysis

Data analysis was performed using the SPSS 22 software. Descriptive statistic indices (mean and standard deviation) of the forces at all the measurements (1 hour, 1 day, and weeks 1 to 6), discoloration after 6 days, and elongation in a 250 g force were calculated for each group. The two-way repeated measures ANOVA was used for inter-group force degradation comparisons and the effect of time on force decay, and the two-way ANOVA was used for inter-group discoloration comparisons. The significance level was considered $P<0.05$.

RESULTS

Inter-group and intragroup force comparisons at all measurements

Inter-group comparison at any time point using the two-way analysis of variance (ANOVA) showed a significant difference between groups ($P<0.001$) (Table I).

Two-way repeated-measures ANOVA was used to evaluate the effect of material type and brand on force decay over time, which showed that the interaction between elastomeric chain brands and time was significant ($F(8.54,281.81) = 4.03$, p-value <0.001). Figure 1 presents the diagram of force decay for these brands over time. Also, the interaction between the material type and time was significant ($F(4.27,281.81) = 29.48$, p-value <0.001), and Figure 2 presents the diagram of force decay for the material type of elastomeric chains over time.

The force in elastomeric chains decreased over time, and the related force decay was calculated to be significant ($F(4.27,281.81) = 694.31$, p-value <0.001) using the two-way repeated measures ANOVA. According to the results, the marginal mean (standard deviation) of force in AO, OR, and GH brands were 54.62, 53.18, and 52.06, respectively. Moreover, the differences of mean forces were calculated to be significant

Table I - Mean and standard deviation of percentages of force in study groups in all time points

Measurement	Force value (Mean±Standard Deviation) in each group						P value*
	GHTS	ORTS	AOTS	GHTP	ORTP	AOTP	
Baseline	100	100	100	100	100	100	
1 hour	77.8±3.4 [c]	75.3±3.8 [c]	78.6±4.7 [c]	70.5±2.8 [b]	65.8±3.7 [a]	67.6±4.3[ab]	< 0.001
1 day	67.0±4.3 [c]	68.3±4.8 [c]	70.6±3.2 [c]	45.0±4.1 [b]	48.8±2.1 [ab]	50.3±3.6 [a]	< 0.001
1 week	62.0±4.0 [c]	61.3±3.5 [c]	63.0±4.2 [c]	41.0±3.4 [a]	43.6±3.6 [a]	43.0±3.8 [a]	< 0.001
2 weeks	58.0±5.7 [c]	61.0±3.4 [c]	61.3±5.2 [c]	39.3±3.3 [a]	40.6±3.7 [a]	42.3±3.6 [a]	< 0.001
3 weeks	56.3±5.5 [c]	58.6±3.9 [c]	60.6±4.1 [c]	37.3±3.1 [a]	41.0±3.8 [a]	42.0±3.1 [a]	< 0.001
4 weeks	57.0±4.5 [c]	57.6±3.1 [c]	59.0±3.8 [c]	37.6±3.1 [a]	39.3±2.8 [a]	41.6±3.9 [a]	< 0.001
5 weeks	55.6±3.6 [c]	58.3±3.6 [c]	58.3±3.6 [c]	37.3±3.1 [a]	38.0±3.6 [a]	40.0±4.1 [a]	< 0.001
6 weeks	54.3±4.3 [c]	55.3±3.7 [c]	57.3±3.1 [c]	36.6±2.8 [a]	37.6±3.9 [a]	38.0±4.6 [a]	< 0.001

*Analysis of Variance (ANOVA); In each row, means marked with different alphabet have significant differences (tukey, P<0.05).

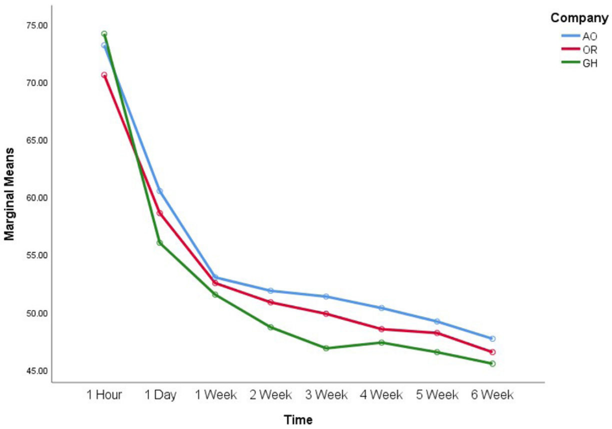

Figure 1 - Diagram of force decay pattern for the study brands over time.

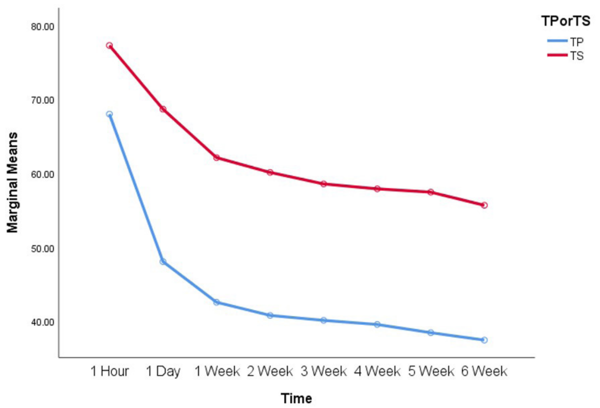

Figure 2 - Diagram of force decay pattern for the material types over time.

between the study brands (F(2,66) = 4.78, p-value = 0.011) using the two-way repeated measures ANOVA. According to the results of Tukey's test for post hoc analysis, the mean force difference between AO and OR was insignificant (p-value = 0.26), while it was significant between AO and GH (p-value = 0.009) and also insignificant between OR and GH (p-value = 0.54). According to the results, the marginal mean (standard deviation) of force in TP and TS materials was 44.36 and 62.21, respectively. Also, the mean force difference between the material types was calculated to be significant (F (1,66) = 692.82, p-value <0.001) using the two-way repeated measures ANOVA.

Elongation changes of elastomeric chains

Table II presents the mean and standard deviation of the study groups' elongations required to deliver 250 g force. Two-way ANOVA was used to evaluate the effect of material type and brand on elongation. As can be seen in Table III, the interaction between "material type (TP or TS) * brand" and the main effects of "material type (TP or TS)" and "brand" on the elongation was significant (P <0.001).

Given the significance of the main effects of material type and brand on elongation, the elongation difference between TP and TS for each brand and the elongation difference between the brands for each material type was evaluated (Tables IV and V).

Color stability of elastomeric chains

Table VI presents the mean and standard deviation of the discoloration of study brands in terms of material type. The effect of brand and material type on discoloration was investigated using two-way ANOVA, and it was shown that the interaction between brand and material type was not significant (F(2,66) = 0.971, p-value = 0.38).

Table II - Mean and standard deviation of elongation in study groups

	GHTS	ORTS	AOTS	GHTP	ORTP	AOTP
Elongation	47.6±2.0	57.2±0.6	42.5±1.0	34.6±1.5	36.3±0.6	35.0±2.4

Table III - Tests of Between-Subjects Effects

Dependent Variable:Elongation					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4784.180[a]	5	956.836	395.464	.000
Intercept	128630.857	1	128630.857	53163.693	.000
TP or TS	3433.079	1	3433.079	1418.907	.000
Company	810.720	2	405.360	167.537	.000
TP or TS* Company	540.380	2	270.190	111.671	.000
Error	159.689	66	2.420		
Total	133574.725	72			
Corrected Total	4943.868	71			

a. R Squared = .968 (Adjusted R Squared = .965); TP or TS* Company = combined effect of material type (TP or TS) and company on elongation; df= degrees of freedom.

Table IV - Comparison of elongation rate between TP and TS of each brand

Brands	Elongation rate (Mean±Standard Deviation)		P-value*
	TP	TS	
AO	35.0±2.4	42.5±1.0	< 0.001
OR	36.3±0.6	57.2±0.6	< 0.001
GH	34.6±1.5	47.6±2.0	< 0.001

* t-test

Table V - Comparison of elongation rate between 3 brands for each material

Material	Elongation rate (Mean±Standard Deviation)			P-value*
	AO	OR	GH	
TP	35.0±2.4	36.3±0.6[a]	34.6±1.5[b]	P=0.044
TS	42.5±1.0[a]	57.2±0.6[b]	47.6±2.0[c]	< 0.001

*Analysis of Variance (ANOVA). In each row, means marked with different alphabet have significant differences (tukey, P<0.05).

Table VI - Mean and standard deviation of discoloration in the study brands in terms of material type

Company	TP or TS		Total
	TP	TS	
AO	21.59±2.61	18.86±1.89	20.22±2.63
OR	20.1±2.63	17.17±1.2	18.63±2.5
GH	20.98±2.05	16.59±2.7	18.78±3.24
Total	20.89±2.45	17.54±2.19	

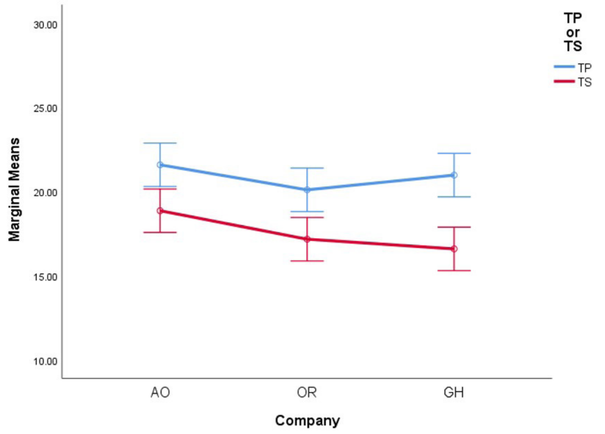

Figure 3 - Diagram of color change for the study brands in terms of material type.

Figure 3 presents the diagram of the discoloration of elastomeric chains by different brands in terms of material type. The difference of mean discolorations between brands was significant (F(2.68) = 3.68, p-value = 0.03). Tukey's post hoc test was used for pair comparisons of study brands, and it was found that the difference of mean discoloration between AO and OR was significant (p-value = 0.04), while it was marginally significant between AO and GH (p-value = 0.07), and insignificant between OR and GH (p-value = 0.97). Also, the difference of mean discoloration between TP and TS chains was significant (F(1,68) = 40.22, p-value <0.001).

DISCUSSION

Previous studies showed great variation in force degradation of elastomeric chains. This variation can be due to material, manufacturing method, force measurement methods, chain transmission methods, storage conditions, and other factors. Thermoset chains were introduced by manufacturers with claims of greater elasticity and better force maintenance during the treatment course. The present study intended to compare the force degradation and color stability of transparent thermoset and thermoplastic chains of three different brands.

According to the results, the force decay of TS chains was significantly lower than TP chains in all brands in all measurements. Similar to our study, Masoud et al. evaluated the force decay of elastomeric chains by American Orthodontics and Ormco brands and found the mean force degradations of 40.63% and 60.9% for the TS and TP chains in a 4-week duration, respectively. Therefore, the force decay of TS chains was 20% lower than TP chains on average [7]. Moreover, studies by Josell et al. [3], Aldrees et al. [11], and Lu et al. [18] reported lower force decay of elastomeric chains are made from TS materials. Also, Masoud et al. evaluated the elastomeric ligatures and found that force decay was lower in TS ligatures (77.41%) than TP ligatures (93.04%) in a 4-week duration [19]. The findings by Kardach et al. were also compatible with the mentioned findings. They compared the mechanical properties of plastic chains (TP) and memory chains (TS) by American Orthodontics in an in vitro study and found that the effectiveness of memory chains was higher than plastic chains in orthodontic treatments because these chains could save their elastic and mechanical properties [4].

The present study showed that the remaining force in 1 hour was 65.8%-78.6% (a force decay of 22%-34%) in chains by AO, OR, and GH. The force degradation rates in 1 hour were reported to be 14%-23% in the study by Baratieri et al. [20], 31%-40% in the study by Bousquet et al. [1], and 28%-33% in the study by Kim et al. [9]. Mirhashemi et al. found the force degradation of memory chains by 3 different companies to be 4.1%-6.2% in 1 hour, while it was 13.9%-20.2% in the conventional chains [21]. The discrepancy between studies can be explained by the variation in materials and study methods. Baseline force is also an important factor in obtaining different results. Lu et al. used the baseline forces of 370, 302, and 240 g and obtained the force degradations of 27%, 24%, and 13%, respectively [18]. Also, studies by Aldrees et al. [11] and Oshagh and Ajami [22] showed a relationship between the baseline force and force degradation. However, some other studies did not find such results [8].

The present study found a remaining force of 45%-70.6% after 1 day in the chains by AO, OR, and GH (force decay of 30%-55%). This finding was compatible with the study by Masoud et al. that found a 30%-57% force degradation in chains by American Orthodontics and Ormco following 1 day [7]. Weissheimer et al. reported a force degradation of 50-55% in 1 day for the chains by four different companies, including American Orthodontics, Morelli, Ormco, and TP Orthodontics [23]. Moreover, the study by Buchmann et al. [24] reported a mean force degradation of 43%-48% in 24 hours for chains by 8 different brands. Also, Kassir et al. reported a force degradation of less than 30% in 24 hours for the chains by the American orthodontics, Ormco, Dentsply, and Rocky Mountain Orthodontics [25]. The discrepancies in these results can be explained by different material types and methods. Given the effect of methodology on obtaining different results, it was shown that storing the chains in artificial saliva [25], the use of transfer jig [19], and sample relaxation before force measurement [5] can affect the force measurement.

The present study showed that a significant amount of force decay occurs during the first week in chains by AO and OR and until the third week for chains by GH. Moreover, the study by Masoud et al. showed that the maximum force decay occurred in the first week in chains by OR and until the second week in chains by AO [7], which was almost compatible with our results. However, Baratieri et al. evaluated three types of elastomeric chains, including plastic chain (AOTP), memory chains (AOTS), and super slick chain, and found a maximum force decay in 1 hour, a medium force degradation in 1 day, and a low force degradation from 1 day to 3 weeks after elongation [20], which was not compatible with our study. This discrepancy can be explained by the study method because the study by Baratieri et al. evaluated the elastomeric chains used in the oral cavities of patients. Also, Masoud et al. evaluated the elastomeric ligatures and found that a considerable amount of force decay occurred in the first four weeks. They explained the lack of force decay after 4 weeks by stating that due to a remarkable force degradation in the first weeks, the force changes after this duration were not significant because the remaining force was slight [19]. Also, Baty et al. showed that force decay patterns varied depending on the manufacturer [26].

The present study showed that the required elongation of TS chains (42.5%-57.2%) was higher than TP chains (34.6%-36.3%) in all the brands. Mirhashemi et al. found that memory chains needed higher elongation to produce the same force than the conventional chains [21], which was compatible with our study. Also, Masoud et al. reported a higher elongation rate of TS chains (47%-49.7%) than the TP chains (24.8%-32.2%) [7]. Also, the present study and two other studies found higher required elongations for thermoset and memory chains than the thermoplastic and conventional chains.

The present study found a discoloration of 16.6%-21.6% for the elastometric chains. The studies by Ruyter et al. [27] and Douglas et al. [28] found a perceptible discoloration threshold of 3.3% and 5.5%, respectively. Therefore, the discoloration of the chains in our study was clinically significant.

The present study showed that the discoloration of TS chains was significantly lower than the TP chains of the same brands. Therefore, TS chains were superior to TP types in terms of color stability. The lowest discoloration was observed in chains by OR, while the highest discoloration was in the chains by AO. However, there was no significant difference between the chains by OR and GH. Talic et al. evaluated the effect of beverages on discoloration and found that elastomeric ligatures by Ormco had the lowest discoloration compared to the ligatures by Unitek and Dentaurum [29].

There are different factors affecting the color stability of elastomeric chains. Discoloration of elastomers is due to chemical degradation and simple mechanical staining and is directly associated with the surface characteristics such as porosity [15,29]. Also, the manufacturing technique is effective in discoloration. Ardeshna and Vaidyanathan found that the resistance to discoloration was higher in ligatures made by injection molding method than the ligatures made by extrusion [14]. Nakhaei et al. performed an in vivo study and found that the type of pigment added to elastomeric ligatures could affect color stability [12]. Thus, the primary colors of elastomers are an important factor in discoloration. Aldrees et al. [11] and Ardeshna and Vaidyanathan [14] found that the degree of discoloration was associated with the primary color, and transparent and light-colored elastomers have higher discoloration than the dark elastomers.

One of the limitations of our study was the fact that force decay and color stability were evaluated under in vitro conditions. However, in in vivo conditions, various oral factors can affect the force decay of elastomers, and also there are different factors, including food, temperature changes, and bacterial flora in the oral cavity that cause simple staining and chemical degradation of the chains, leading to chain discoloration [12]. These factors are not considered or are limited under in vitro conditions. Also, the discoloration in our study was evaluated using a spectrophotometer, while the findings of this instrument are not the same as the human perception of color change.

CONCLUSION

According to the present study results, we concluded that thermoset chains had significantly lower force decay and a higher required elongation than the thermoplastic chains. Moreover, thermoset chains had significantly better color stability than the thermoplastic chains.

Author Contributions

Saeid Foroughi MOGHADDAM designed the study, wrote the manuscript.

Mohammad Damavandi KAMALI designed the study, performed the measurements, and wrote the manuscript.

Conflict of Interest

None.

Funding

This research was performed by financial support of the Tabriz University of Medical Sciences.

Regulatory Statement

None.

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Date submitted: 2020 Nov 07
Accept submission: 2021 Feb 08