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Invivo and invitro tensile properties of orthodontic elastomeric chains – A comparative study

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Abstract

Aim: This study was to evaluate the permanent elongation and tensile strength of elastomeric chains in vivo and in vitro of three commonly available brands.

Materials and Method: Two types (open & closed chains) of three brands of elastomeric modules producing six groups were included in the study. Specimens were measured by digital caliper and classified into four groups based on their ageing state: (a) as received; (b) subjected to a 24 hours steady strain in air determined as 50% of original length; (c) exposed intraorally for 24 hours; and (d) retrieved following 3 weeks of intraoral exposure. The final lengths of all the specimens were measured and mean percentage elongation was calculated for each group and was analysed with two-way ANOVA. For tensile strength, the specimens were subjected to the above said conditions and were subjected to tensile stress and their behavior was analysed with three-way ANOVA and Tukey's multiple comparison test.

Results: The results showed that open E-chains show more percentage elongation compared to closed types. The tensile strengths of the E-chains in all the groups decreased after being subjected to intraoral conditions. The decrease in the tensile strength was proportional to the time in the oral cavity.

Conclusion: Open E-chains have higher percentage elongation compared to closed E- chains in vitro but closed E-chains have higher percentage elongation compared to open E-chains in vivo. Among the different test conditions, the maximum percentage elongation was seen after 3 weeks intraoral stretching and least by the E-chains stretched 24 hours in air. The tensile strength was most in the in vitro conditions and least after three weeks stretching intraorally.

Clinical Significance: The most important problem of the E-chains is their force decay during the time so being aware of the various factors that can affect their characteristic and force decay pattern is essential. This can help practitioners to use chains in a better way.

Keywords: Elastomeric chains; Force decay; Mechanical properties; Permanent elongation; Tensile strength

Introduction

Elastomeric chains were introduced to the orthodontic profession in the 1960s, and are now integral part of many practices.(1) They are used for correcting rotations, consolidating spaces, and retracting canines. Force decay in these materials is significant and has been a clinical problem.(2) The polymers are not ideal elastic materials because their mechanical properties change with time and temperature.(3) This study was to evaluate the permanent elongation and tensile strength of elastomeric chains in vivo and in vitro of three commonly available brands.

Materials and Method

This study was done in the Department of Orthodontics of dental institution and approval of the ethical committee of the institution was taken to conduct the study. Two types (open and closed i.e., with and without an intermodular link) of three brands of elastomeric module producing six groups were included in the study (Table 1).

Table 1: The elastomeric chains included in the study

Group	Brand (Manufacturer)	Design
I	Alastik (3M/Unitek, Monrovia, California, USA)	Closed
II	Sunburst (GAC, Bohemia, New York, USA)	Closed
III	OrthoOrganizers (San Marcos, California, USA)	Closed
IV	Alastik	Open
V	Sunburst	Open
VI	OrthoOrganizers	Open

For permanent elongation: In vitro specimens were prepared by cutting multiple series of specimens of each type and brand containing ten samples each (total 60), having equal numbers of loops (6) from the spools, and in vivo specimens were taken depending on the patient's needs, with the use of a sharp ligature cutter. Care was taken to avoid extended handling during cutting as this might have incorporated stresses in the material prior to testing.

The initial length **(L0)** of the prepared specimens was measured with a digital caliper. The specimens were classified into four groups based on their ageing state:

1. Elastomeric in the as received state;
2. Chains subjected to a 24 hour steady strain in air, determined as 50 per cent of its original length;
3. Modules elongated intraorally at approximately 50 per cent extension relative to the as received state. Specimens were retrieved following 24 hours of exposure in the oral cavity of the patient of good oral health under orthodontic treatment with edgewise, 0.022 inch, Roth prescription, not under any medication. This facilitated comparison between material alterations induced by in vitro stretching and intraoral extension during the same time period.
4. Chains retrieved after a 3 week exposure to the oral environment of patients receiving orthodontic therapy with brackets identical to the 24 hour retrieval experiment. The modules were again elongated approximately 50 per cent relative to the as received state.

All the in vitro specimens were stretched 50% of their original length in a framework consisting of a metallic box, screws (30nos) and nuts (60nos) and 1mm hard round stainless steel wire hooks soldered to the heads of the screws which were placed on either side of the metallic box (Fig. 1). The distance between the two hooks was adjusted and measured with the help of a digital caliper to ensure that all the specimens were elongated 50% of their original lengths. Total 60 samples were placed in the framework, 15 at a time, to test the permanent elongation. The framework was placed at room temperature for 24 hours.

In vivo specimens were fabricated depending upon patient's needs and all the intraorally exposed specimens were retrieved and rinsed with copious amounts of distilled water to remove the loosely bound intraorally formed integuments. The final length **(L)** of the specimens was measured at the end of the testing period. The percentage elongation was calculated using the formula $\varepsilon = [(L - L0)/ L0].100$

For tensile strength test: In vitro specimens were fabricated by cutting 12 loops of each chain spool of the material included in the study; in this case the six central loops were subjected to stretching and the three loops on each side were used to alleviate the excessive stress concentration on the terminal loops.

In vivo specimens of each brand and type were taken depending on patient's need. Ten specimens of the six material groups exposed to the four conditions of the experiment were mounted on a calibrated testing machine (LLOYD instruments, LR50K) and were subjected to tensile extension at a rate of 5mm/minute until failure. The testing configuration consisted of fabricating two hooks from 1mm diameter stainless steel wire and attaching the elastic chain to hooks. A choice of a large diameter round wire was to avoid the edges of the rectangular wire, which may have applied increased stress on the chain. A 1mm wire is also sufficiently stiff to exclude any absorption of stress during testing. The modules were subjected to tensile stress and the breaking force (N) was recorded for each specimen.

The results of the elongation experiment were analysed with a two-way ANOVA with brand and type (open or closed chains) serving as discriminating variables, while the results of the tensile strength measurement were statistically analysed with a three-way ANOVA with brand, design (closed versus open) and state (as-received, 24 hour stretched in air, 24 hours intraoral, and 3 weeks intraoral) variables. Further differences among groups were examined with Tukey's multiple comparison test.

Results

Table 2 shows the results of mean permanent elongation measurements following extension in air for 24 hours. Group VI and Group IV underwent the highest elongation followed by group III and Group V. The least elongation was seen in Group I and Group II.

There were statistically significant differences in Groups when compared for brand and type.

Fig. 2 shows the bar graph representation of mean permanent elongation (percentage) of chain groups after 50% extension in air for 24 hours.

Fig. 1: Frame work and jigs used in the study

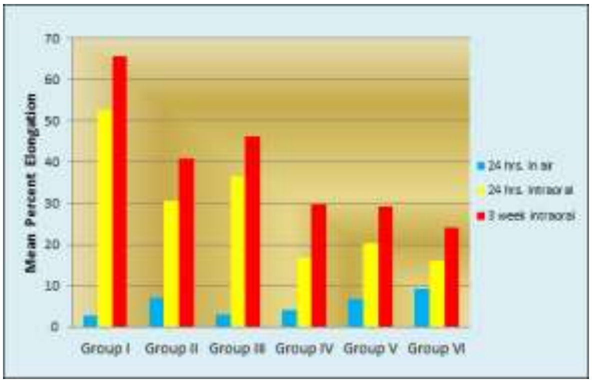

Fig. 2: Mean permanent elongation (percentage) of chain groups after 50% extension in air for 24 hrs, intraorally for 24 hrs and intraorally for 3 weeks

Table 2 shows the results of mean permanent elongation measurements following extension intraorally for 24 hours. Group I and Group II underwent maximum elongation followed by Group IV and Group III, whereas Group V and Group VI presented the least elongation.

There were statistically significant differences in Groups when compared for brand and type.

Fig. 2 shows the bar graph representation of mean permanent elongation (percentage) of chain groups after 50% extension intraorally for 24 hours.

Table 2 shows the results of mean permanent elongation measurements following extension intraorally for 3 weeks. Group I and Group II presented the highest elongation followed by Group IV and Group V, whereas Group III and Group VI presented with the least elongation.

There were statistically significant differences in Groups when compared for brand and type.

Fig. 2 shows the bar graph representation of mean permanent elongation (percentage) of chain groups after 50% extension intraorally for 3 weeks.

Statistical comparison between the groups for the four treatments (i.e., as received, 24 hours stretched in air, 24 hours exposure intraorally and 3 weeks intraorally), result indicates that there were statistically significant differences among the groups for all the four conditions.

Table 3 shows the results of mean tensile strength measurements for all four treatment conditions. For as received samples, the highest fracture values were recorded for Group IV and Group V followed by Group I and Group II, whereas the least fracture values were recorded for Group VI and Group III.

For samples after 24 hours extension in air, the highest fracture values were recorded for Group IV and Group V followed by Group I and Group II whereas the least fracture values were recorded for Group III and Group VI.

For samples after 24 hours exposure intraorally, the highest fracture values were recorded for Group IV and Group VI followed by Group II and Group III where as the least fracture values were recorded for Group V and Group I.

For samples after 3 weeks exposure intraorally, the highest fracture values were recorded for Group IV and Group V followed by Group I and Group III where as the least fracture values were recorded for Group VI and Group II.

Fig. 3 Shows the bar graph representation of the mean tensile strengths for the four different treatment conditions i.e., as received, 24 hours stretched in air, 24 hours exposure intraorally and 3 weeks intraorally.

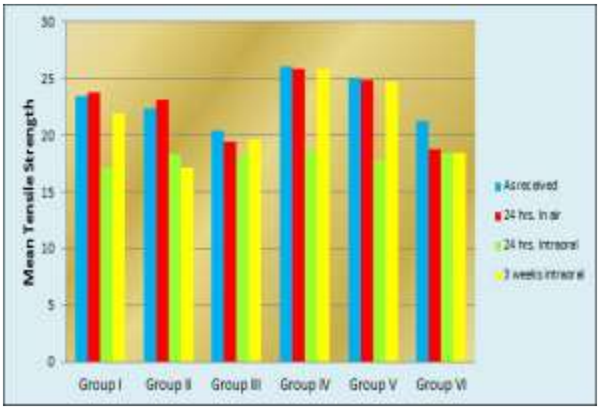

Fig. 3: Mean pattern of tensile strength of the chains subjected to 50% extension of their original length, as received, 24 hours in air, 24 hours intraorally and 3 weeks intraorally

Table 2: Mean permanent elongation (percentage) of chain groups after 50% extension of their original length

Groups	24 Hours in air	24 hours intraoral	3 weeks intraoral
	Mean ± SD	**Mean ± SD**	**Mean ± SD**
I	2.83 ± 0.44	52.56 ± 0.52	65.74 ± 0.43
II	3.10 ± 0.36	36.52 ± 0.43	46.15 ± 0.34
III	6.78 ± 0.33	20.20 ± 0.29	29.22 ± 0.25
IV	7.09 ± 0.34	30.64 ± 0.46	40.68 ± 0.36
V	4.15 ± 0.27	16.77 ± 0.28	29.82 ± 0.37
VI	9.30 ± 0.63	15.95 ± 0.34	24.19 ± 0.24
P value Two way ANOVA	Brand: P<0.001** Type: P<0.001**	Brand: P<0.001** Type: P<0.001**	Brand: P<0.001** Type: P<0.001**

Table 3: Mean pattern of Tensile strength (N) of the chains subjected to 50% extension of their original length

Groups	As received		24 hours (air)		24 hours intraoral		3 weeks intraoral	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
I	23.45	0.56	23.81	0.34	17.08	0.36	21.95	0.28
II	22.39	0.67	23.12	0.51	18.34	0.74	17.15	0.79
III	20.38	0.53	19.40	0.61	18.16	0.81	19.58	0.65
IV	26.06	0.47	25.81	0.60	18.53	0.59	25.85	0.45
V	25.02	0.40	24.82	0.42	17.80	0.53	24.75	0.38
VI	21.24	0.47	18.71	0.61	18.46	0.41	18.47	0.42
P value	<0.001**		<0.001**		<0.001**		<0.001**	

Statistical comparison between the groups for the four treatments (i.e., as received, 24 hours stretched in air, 24 hours exposure intraorally and 3 weeks intraorally), result indicates that there are statistically significant differences among the groups for all the four conditions.

Significant Fig.:
+ Suggestive significance $0.05<P<0.10$
* Moderately significant $0.01<P \leq 0.05$
** Strongly significant $P \leq 0.01$

Discussion

The results of the present study can be discussed under the following headings:

1. **Comparison of the percentage elongation between the groups**

   a. **Comparison of the percentage elongation between the groups following 50% elongation for 24 hours in air:**

After 50% elongation for 24 hours in air (in vitro), the maximum percentage elongation of 9.30±0.63 was seen in the Group VI (open E-chain, OrthoOrganizers). The minimum percentage elongation of 2.83± 0.44 was seen in the Group I (closed E-chain, Alastik). This indicated that OrthoOrganizers open E–chain is elongated the most after 24 hours in air and Alastik closed E-chain the least. This is in accordance with the findings of Kuster et al, who demonstrated that 50% to 75% loss of initial force occurs in these products over 3 to 4 weeks, with the most of the loss within the first hour.[4]

On comparison of the percentage elongation within the brands it was seen that the open E-chains showed more percentage elongation than the closed types in both Alastik and OrthoOrganizers. But in the GAC group the closed E-chain showed more elongation when compared to the closed type of the same brand (7.09 closed vs. 6.78 open). This indicated that on the whole open E-chains are more susceptible to permanent elongation following plastic prestrain.

Comparing between the different brands for open E-chains it was seen that Alastik company E-chains showed the least elongation with 4.15 ± 0.27 and the OrthoOrganizers the most with "9.30 ± 0.63". Among the closed E-chains the maximum elongation (7.09 ± 0.34) was in the GAC group and the least (2.83 ± 0.44) in the Alastik group. This indicated that Alastik E-chains showed the least permanent deformation following 50% elongation after 24 hours in the air.

This is in agreement with the findings of Andreasen[5] and Bishara[6] who compared the percentage elongation between latex elastics and Unitek C-1 Alastik modules in a simulated interarch space closure and interarch forces and reported that Alastiks suffered a 74% loss of force degradation after 24 hours whereas latex elastics lost 42% only. Hershey et al in contrast found 50% force loss after the first day, with 40% of the original force remaining after 4 weeks for the Alastik E-chains.[7] Brooks et al claimed that 50% of the force degradation can be reduced by a combination of pre stretching and heat application from their study.[8]

All the above differences in percentage elongation were statistically significant (p<0.001) except for that between Groups I and III and that between Groups II and V.

   b. **Comparison of the percentage elongation between the groups following 50% elongation for 24 hours intraoral:**

After 50% elongation for 24 hours intraorally (in vivo), the maximum percentage elongation of 52.56 ± 0.52 was seen in Group I (closed E-chain, Alastik). The minimum percentage elongation of 15.95 ± 0.34 was seen in Group VI (open E-chain, OrthoOrganizers).This indicated that OrthoOrganizers open E–chain is elongated the least after 24 hours intraorally and Alastik closed E-chain the most. This is in agreement with the findings of Kuster et al that E-chains stored in air were extended to 82% and 115% and retained higher initial force when compared with E-chains placed in vivo at 100% extension and concluded that initial extension of E-chains from its original length differs between the products to provide an optimal force level.[1]

On comparison of the percentage elongation within the brands it was seen that on the whole closed E-chains are more susceptible than open E-chains to permanent elongation after 24 hours in the oral cavity. Kovatch et al suggested that clinically these modules should be stretched slowly to position. They demonstrated that the load- extension curves of E-chains were found to be sensitive to both the degree and the rate of extension.(9)

Comparing between the different brands for open E-chains it was seen that OrthoOrganizers E-chains showed the least elongation with 15.95 ± 0.34 and the GAC brand the most with 20.20 ± 0.29. Among the closed E-chains the maximum elongation (52.56 ± 0.52) was in the Alastik group and the least (30.64 ± 0.46) in the GAC group. This indicated that GAC closed E-chains showed the least permanent deformation following 50% elongation after 24 hours intraorally. This agrees with the study by Renick et al who demonstrated that there may be significant differences in clinical force- degradation behavior between the products of different brands.(10)

All the above differences in percentage elongation were statistically significant ($p<0.001$) except for that between Groups I and III and that between Groups II and V.

c. **Comparison of the percentage elongation between the groups following 50% elongation for three weeks intraoral:**

After 50% elongation for three weeks intraorally (in vivo) the maximum percentage elongation of 65.74 ± 0.43 was seen in the Group I (closed E-chain, Alastik). The minimum percentage elongation of 24.19 ± 0.24 was seen in the Group VI (open E- chain, OrthoOrganizers). This indicated that OrthoOrganizers, open E–chain was elongated the least after three weeks intraorally and Alastik closed E-chain the most.

On comparison of the percentage elongation within the brands, it was seen that on the whole closed E-chains are more susceptible than open E-chains to permanent elongation after three weeks in the oral cavity. This is in agreement with the findings of Ash et al who showed that the force decay in vivo is significantly greater than in air.(11)

Comparing between the different brands for open E-chains, it was seen that the OrthoOrganizers E-chains showed the least elongation with 24.19 ± 0.24 and the Alastik brand the most with 29.82 ± 0.37. Among the closed E-chains the maximum elongation (65.74 ± 0.43) was in the Alastik group and the least (40.68 ± 0.36) in the GAC group. This indicated that the GAC closed E-chains showed the least permanent deformation following 50% elongation after three weeks intraorally. This is in agreement with the findings of Eliades T. et al who demonstrated that E-chains showed the most degradation characteristics after 3 weeks in the oral cavity.(12)

All the above differences in percentage elongation were statistically significant ($p<0.001$) except for that between Groups I and III and that between Groups II and V.

2. **Comparison of the tensile strengths between the groups.**

a. **Comparison of the tensile strengths between the groups when received:**

The Group IV showed the maximum tensile strength, 26.06 N and the Group III the least tensile strength 20.38 N after 50% elongation in air for 24 hours. This indicates that open E-chains of the Alastik brand have the most tensile strength and the closed E-chain of the OrthoOrganizers the least before any prestretching. This agrees with the findings of Kim et al who demonstrated that the effects of prestretching on force decay of elastomeric chains were noted mainly in the first hour. Thus according to them the clinical value of prestretching a synthetic elastomeric chain is questionable.(13)

b. **Comparison of the tensile strengths between the groups after 24 hours in air (in vitro):**

The Group IV showed the maximum tensile strength, 25.81 N and the Group III the least tensile strength 19.40 N after 50% elongation in air for 24 hours. This indicates that open E-chains of the Alastik brand has the most tensile strength and the closed E-chain of the OrthoOrganizers the least following prestretching for 24 hours in air. This is in accordance with the findings of Kovatch et al who demonstrated that open E-chains have a very high tensile strength under clinical conditions.(9) This also agrees with the findings of Nightingale et al who showed that initial forces resulted in high force decay.(14)

c. **Comparison of the tensile strengths between the groups after 24 hours intraorally (in vivo):**

Group IV showed the maximum tensile strength, 18.53 N and Group III the least tensile strength 17.08 N after 50% elongation intraorally for 24 hours. This indicates that open E-chains of the Alastik brand has the most tensile strength and the closed E-chain of the OrthoOrganizers the least following stretching for 24 hours intraorally. This is in accordance with the study by Gioka et al where they assessed the force relaxation of latex elastics occurring within 24 hours of extension and proposed that most of the relaxation occurs within the first 3–5 hours after extension, regardless of the size, the manufacturer, or the force level of the elastic.(15)

d. **Comparison of the tensile strengths between the groups after three weeks intraorally (in vivo):**

Group IV showed the maximum tensile strength, 25.85 N and Group II the least tensile strength 17.15 N after 50% elongation in air for 24 hours. This indicates that open E-chains of the Alastik brand has the most tensile strength and the closed E- chain of the OrthoOrganizers the least following stretching for three weeks intraorally.

Statistical analyses showed a statistically significant difference ($p<0.001$) between the tensile strengths of both open and closed E-chains of the three bands, in all the test conditions. This is in agreement with the findings of Ash et al who showed that after 3 weeks the Alastiks, at the given level of initial activation; lose 20% more force intraorally than in the air.[11] In contrast to this are the findings of Eliades T. et al who found no correlation between specimen treatment and the tensile strength of elastomers.[12]

Conclusion

The results showed that open E-chains show more percentage elongation compared to closed types. The Alastik brand showed the most elongation after being subjected to oral conditions. The tensile strengths of the E-chains in all the groups decreased after being subjected to intraoral conditions. The decrease in the tensile strength was proportional to the time in the oral cavity.

Clinical Significance

Force decay behavior of elastomeric chains is influenced by various factors such as design, manufacturing techniques, environmental conditions, color and etc. As this is essential for clinicians to know the properties of all materials they use, this study was done to publish a comprehensive information about E-chains, their characteristics and factors affecting them in orthodontic treatments.

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