Deformation of elastomeric chains related to the amount and time of stretching

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Objective: Investigate a potential relationship between degree of stretching and resulting permanent deformation of elastomeric chains (ECs) as well as whether or not stretching time has any bearing on the degree of permanent deformation.

Methods: Five-module segments of closed elastomeric chains manufactured by 3M Unitek were stretched to 10-100% of their original length in devices especially designed for this purpose, remaining submerged in artificial saliva at 37 ± 1° C and were removed sequentially after 1, 2, 3 and 4 weeks. Upon removal, each segment was measured and once recorded the values were analyzed statistically with the purpose of assessing the degree of permanent deformation.

Conclusions: It was concluded that permanent deformation is directly proportional to the degree of stretching of the ECs assessed. The mean percentages found were 8.4% to 10% of stretching, and exceeding 20% (21.3%) when stretched by 40%, and reaching 56.6% permanent deformation when stretched 100% of their original length. Finally, the highest percentage of permanent deformation occurred during the first week and was not statistically significant after this period.

Keywords: Elastomers. Tensile strength. Permanent deformation.

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INTRODUCTION AND LITERATURE REVIEW

Among the various force-producing mechanisms used in orthodontics to move teeth as physiologically as possible through the alveolar bone, elastomeric chains (ECs) are undoubtedly the most widely employed in daily practice.[14,15]

EC insertion and removal requires little chair time and is not dependent on patient compliance. Furthermore, ECs are inexpensive and compatible with soft tissues.[8] When stretched, ECs generate elastic potential energy that can be transformed into mechanical energy, which in turn produces tooth movement. Given that they are made from amorphous polyurethane-based polymers, ECs exhibit characteristics of both rubber and plastic, which accounts for their elasticity.[5] The polymers are composed of primary and secondary links with weak molecular attraction that initially display a spiral pattern. When this pattern is subjected to the application of forces it undergoes deformation, causing ECs to be arranged linearly through crosslinking. The weak secondary links allow the spiral pattern to be transformed into a linear pattern while recovery of the initial structure becomes possible by means of crosslinking.[16] Permanent deformation occurs when the polymer is stretched beyond its elastic limit, causing disruption of crosslinks. However, certain factors influence EC performance, such as rapid force decay after stretching, i.e., inability to develop constant forces for an extended period of time, thereby impairing their effectiveness.[1,3,7,13,14,16] Additionally, ECs are influenced by temperature variations, salivary pH and the degree of stretching to which they are subjected.[14] In the oral environment, ECs absorb water, saliva and pigments, eventually undergoing chemical degradation, which results in the weakening of intermolecular forces, thereby decomposing their internal links. This leads to the onset of force decay processes, lack of dimensional stability and permanent deformation, making it difficult to determine the actual force magnitude being delivered to a given tooth.[3] Therefore, this *in vitro* study aimed to investigate the potential relationship between degree of stretching and resulting permanent deformation of elastomeric chains (ECs), as well as determine whether or not stretching time has any bearing on the degree of permanent deformation of ECs.

MATERIAL AND METHODS

For this research, closed gray ECs (CK Chain Spool - 3M Unitek), were carefully sectioned into segments of five modules each, with an initial length of 10 mm, ignoring the two ends of the segments, whose function was only to facilitate EC stretching. Four acrylic plates were fabricated and perforated for the insertion of 20 stainless steel pins with 0.2 cm diameter and 1.5 cm length arranged in parallel in 10 pairs with increasing distance between them in 1.0 mm increments, starting from 1.1 cm and ending with 2.0 cm. Ten EC segments were fitted to each pair of pins with the aid of a Mathieu needle holder, and were thus stretched to 10-100% of their original length. To prevent the pins from approaching each other due to the tension produced in stretching the ECs, a pin of equal length was fitted between all pairs of pins as shown in Figure 1. The plates were immersed in a stainless steel case containing artificial saliva with the following composition: Calcium 1.5 mmol L-1, Phosphate 0.9 mmol L-1, KCL 150 mmol L-1 in cacodylate buffer, 0.1 mol L-1 pH 7.0, Fluorine 0.05 mg/mL (1.1 mL solution/mm^2). This case was kept closed and in water bath at 37 ± 1° C in a soaking tub (Fig 2). These plates were first identified with a black OHP marker pen, according to the duration of the experiment. It is noteworthy that the water level was kept below the stainless steel lid, thus preventing contamination of the artificial saliva. Subsequently, the plates were removed sequentially after 1, 2, 3 and 4 weeks. Once retrieved from the saliva and blotted dry, each elastomeric segment was fitted to a measuring device especially made for this purpose consisting of a pin fixed to a wooden base, covered with graph paper (Fig 2). One end of the EC was seated in the pin and its final length recorded on graph paper. Thereafter, the length of each EC was measured and recorded with a caliper. Each week, the artificial saliva was replaced. It was first pre-heated in a container up to a temperature of 37 ± 1 °C, thereby averting changes in temperature.

Data were statistically analyzed by analysis of covariance (ANCOVA) with the purpose of checking whether there was a statistically significant difference between time and degree of stretching. Level of significance was set at 5% ($p = 0.0556$), to identify possible differences between groups.

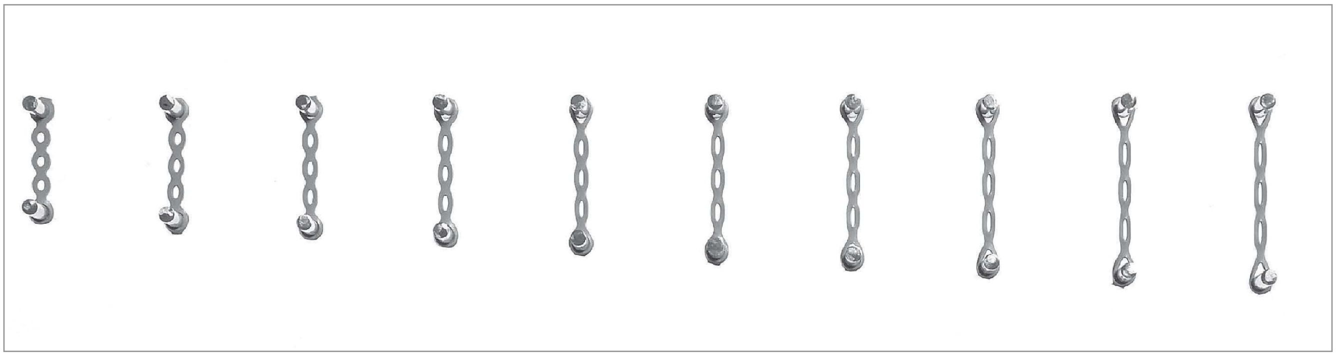

Figure 1 - Acrylic plate with stretched elastomeric chains.

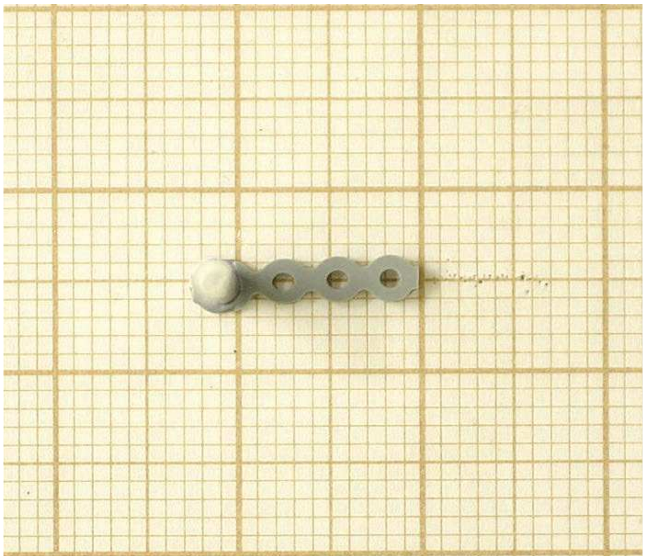

Figure 2 - Soaking tub used in the experiment.

RESULTS

Overall, it was found that permanent deformation of ECs was proportional to increases in stretching (Table 5). However, it was found that the mean deformation observed in the second, third and fourth weeks differed significantly from the mean stretching observed in the first week. No statistically significant differences were found in comparing the second to the third, the second to the fourth as well as the third to the fourth weeks (Table 7).

The results found in each week, according to time and degree of stretching, are presented in Tables 1, 2, 3 and 4; mean and standard deviation values reflecting the behavior of the variable *deformation* according to week and degree of stretching are shown in Table 5.

In order to assess to what extent the mean deformation was similar in all weeks, the test of equality of inclination coefficient was applied with a 5% level of significance ($p = 0.0556$). This was necessary because the hypothesis which assumed that the mean deformation in at least one week was influenced by the percentage separation between the pins was rejected. The magnitude of these differences can be seen in Table 6, in the inclination coefficient column. Table 6 also shows the mean stretching throughout the levels of separation for each week. The term *intercept* refers to the estimated mean deformation in millimeters in each week, irrespective of distance. The expression *inclination coefficient* refers to the mean change in one distance unit (10%). In the first week, regardless of distance, a mean deformation of 0.0479 mm per 10% stretching was found, i.e., in order to reach a mean deformation of 10% to 50% stretching, or 20% to 60%, one can simply multiply 0.0479 mm by 5, and a deformation of 0.23 mm is obtained. In the second week, the deformation was 0.0564 mm, in the third was 0.0530, and in the fourth, 0.0544 mm.

Based on the analysis of covariance (ANCOVA), it was found initially that, for all weeks, the mean deformation depends linearly (Fig 3) on the percentage of pin stretching ($p < 0.001$), i.e., in at least one of the weeks the mean deformation was influenced by the percentage of pin stretching (independent variable).

Since the hypothesis of lack of parallelism is not rejected yet, the mean elongations were compared between weeks (distances between the adjusted straight lines). These results can be seen in Figure 4.

Table 1 - Results, in mm, obtained after stretching for one week.

1st week	STRETCHING (mm) Initial length = 10 mm									
Trial	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	10.7	11.2	11.5	11.9	12.5	13.0	13.2	13.8	14.5	15.0
2	10.7	11.1	11.3	12.0	12.1	13.0	13.3	13.7	14.6	15.1
3	10.8	11.0	11.5	12.0	12.5	13.0	13.2	13.9	14.5	15.0
4	10.7	11.1	11.5	12.0	12.3	13.0	13.2	13.9	14.6	15.0
5	10.7	11.1	11.5	12.0	12.4	13.0	13.2	13.8	14.6	15.0
6	10.7	11.0	11.5	12.0	12.5	13.0	13.3	13.7	14.6	15.1
7	10.7	11.1	11.5	12.0	12.5	13.0	13.3	13.7	14.5	15.1
8	10.7	11.2	11.5	12.0	12.5	13.0	13.2	13.8	14.5	15.0
9	10.7	11.1	11.4	12.0	12.5	13.0	13.2	13.8	14.6	15.0
10	10.7	11.1	11.5	12.0	12.5	13.0	13.2	13.9	14.5	15.1

Table 2 - Results, in mm, after stretching for two weeks.

2nd week	STRETCHING (mm) Initial length = 10 mm									
Trial	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	10.9	11.0	11.9	12.0	12.9	13.0	13.7	14.4	15.4	16.4
2	10.8	11.0	11.9	12.0	12.8	13.0	13.9	14.4	15.0	15.9
3	10.9	11.3	11.6	12.5	12.8	13.0	13.9	14.4	15.0	15.9
4	10.8	11.0	11.6	12.0	12.8	13.0	13.9	14.4	15.2	15.9
5	10.9	11.1	11.7	12.0	12.8	13.0	13.9	14.4	15.2	15.9
6	10.9	11.2	11.9	12.0	12.9	13.0	13.8	14.4	15.4	16.1
7	10.8	11.3	11.9	12.0	12.9	13.0	13.9	14.4	15.0	16.3
8	10.9	11.1	11.9	12.0	12.8	13.0	13.8	14.4	15.0	15.9
9	10.8	11.0	11.9	12.0	12.8	13.0	13.8	14.4	15.0	16.0
10	10.9	11.0	11.9	12.0	12.8	13.0	13.9	14.4	15.0	15.9

Table 3 - Results, in mm, after stretching for three weeks.

3rd week	STRETCHING (mm) Initial length = 10 mm									
Trial	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	10.9	11.1	11.9	12.0	12.8	13.0	13.9	14.1	15.0	15.7
2	10.9	11.1	11.9	12.0	12.5	12.9	13.9	14.1	15.0	15.7
3	10.9	11.1	11.9	12.0	12.8	13.0	13.8	14.1	15.0	15.7
4	10.9	11.1	11.9	12.0	12.6	13.0	13.9	14.1	15.0	15.7
5	10.9	11.1	11.9	12.0	12.8	13.0	13.8	14.1	15.0	15.7
6	10.9	11.1	11.9	12.0	12.7	12.9	13.9	14.1	15.0	15.7
7	10.9	11.1	11.9	12.0	12.8	13.0	13.9	14.1	15.0	15.7
8	10.9	11.1	11.9	12.0	12.8	13.0	13.8	14.1	15.0	15.7
9	10.9	11.1	11.9	12.0	12.5	13.0	13.9	14.1	15.0	15.7
10	10.9	11.1	11.9	12.0	12.8	13.0	13.9	14.1	15.0	15.7

Table 4 - Results, in mm, after stretching for four weeks.

4th week	STRETCHING (mm) Initial length = 10 mm									
Trial	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	10.9	11.5	12.0	12.1	12.9	13.3	14.0	14.5	15.1	15.8
2	10.9	11.4	12.0	12.2	12.9	13.3	14.0	14.8	15.0	16.0
3	10.9	11.4	11.9	12.2	12.9	13.0	14.0	14.7	15.5	15.9
4	10.9	11.4	11.9	12.2	12.9	13.1	14.0	14.7	15.3	15.9
5	10.9	11.4	12.0	12.2	12.9	13.2	14.0	14.8	15.0	15.9
6	10.9	11.5	12.0	12.2	12.9	13.2	14.0	14.6	15.5	16.0
7	10.9	11.4	12.0	12.9	12.9	13.0	14.0	14.5	15.1	15.9
8	10.9	11.4	12.0	12.9	12.9	13.3	14.0	14.7	15.3	15.8
9	10.9	11.4	12.0	12.9	12.9	13.3	14.0	14.8	15.0	15.9
10	10.9	11.5	12.0	12.9	12.9	13.0	14.0	14.8	15.2	15.9

Table 5 - Mean and standard deviation values, in mm, for each degree of stretching vs. week combination.

Stretching	1st week	2nd week	3rd week	4th week	Mean ± SD
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
10%	10.71 ± 0.03	10.86 ± 0.05	10.90 ± 0.00	10.90 ± 0.00	10.84 ± 0.08
20%	11.10 ± 0.07	11.10 ± 0.12	11.10 ± 0.00	11.43 ± 0.05	11.18 ± 0.16
30%	11.47 ±0.07	11.82 ± 0.13	11.90 ± 0.00	11.98 ± 0.04	11.79 ± 0.21
40%	11.99 ±0.03	12.05 ± 0.16	12.00 ± 0.00	12.47 ± 0.37	12.13 ± 0.28
50%	12.43 ±0.13	12.83 ± 0.05	12.71 ± 0.13	12.90 ± 0.00	12.72 ± 0.20
60%	13.00 ± 0.00	13.00 ± 0.00	12.98 ± 0.04	13.17 ± 0.13	13.04 ± 0.10
70%	13.23 ± 0.05	13.85 ± 0.07	13.87 ± 0.05	14.00 ± 0.00	13.74 ± 0.31
80%	13.80 ± 0.08	14.40 ± 0.00	14.10 ± 0.00	14.69 ± 0.12	14.25 ± 0.34
90%	14.55 ± 0.05	15.12 ± 0.17	15.00 ± 0.00	15.20 ± 0.19	14.97 ± 0.28
100%	15.04 ± 0.05	16.02 ± 0.19	15.70 ± 0.00	15.90 ± 0.07	15.66 ± 0.40
Mean	12.732	13.105	13.026	13.264	13.03
SD	1.39	1.65	1.54	1.58	1.55

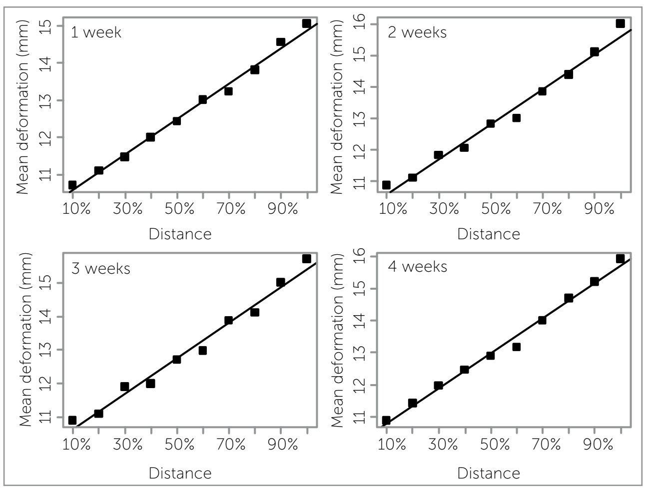

Figure 3 - Dispersion of mean deformation vs. distance. The straight line shows adjustment by least squares.

Table 6 - Estimates of parameters for adjusted models.

Week	Intercept	Inclination coefficient	R^2
1st Week	12.732 (0.004)*	0.0479 (0.0014) *	0.9919
2nd Week	13.105 (0.076) *	0.0564 (0.0027) *	0.9805
3rd Week	13.026 (0.073) *	0.0530 (0.0025) *	0.9796
4th Week	13.264 (0.051) *	0.0544 (0.0018) *	0.9905

R^2 = Adjusted determination coefficient; * standard deviation.

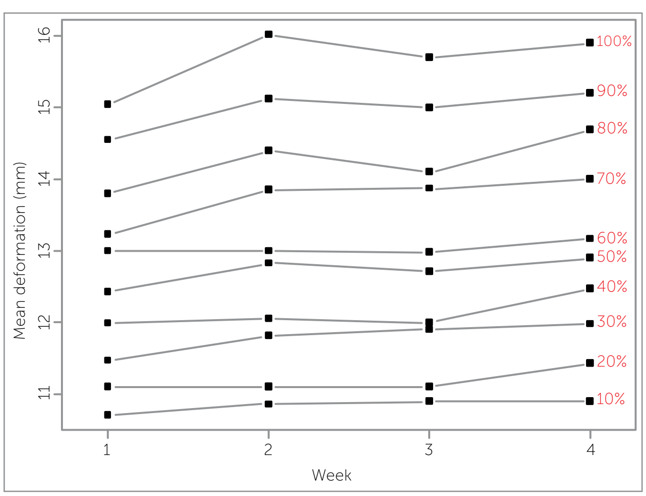

Figure 4 - Mean deformation, over the weeks, for each of the distances.

Table 7 - Comparison between mean deformations.

	1st week	2nd week	3rd week	4th week
1st Week		0.0004*	0.0037*	< 0.0001*
2nd Week	0.0004*		0.4086	0.1012
3rd Week	0.0037*	0.4086		0.0165*
4th Week	< 0.0001*	0.1012	0.0165*	

* = Statistically significant difference.

In comparing the mean deformations, statistically significant differences were detected only in the first week, compared to the others. Table 7 demonstrates a comparison between mean deformations in all weeks.

In this study it was found that the percentage of force decay rises as immersion time increases. However, a reversal – though not statistically significant – was observed between the means of the second and third weeks (Table 5 and Fig 4).

DISCUSSION

To be effective in their function, ECs should produce an appropriate magnitude of force for a certain period of time.[10] However, it is known that ECs cannot generate constant forces for a long period of time since their elastic properties are altered over time, causing permanent deformation and, consequently, loss of tension. The inability of elastic materials to return to their original size after undergoing substantial deformation and releasing the tensile forces applied to them, is defined as plastic, or permanent, deformation.[4] The effects of this plastic deformation are manifested by the decrease of these materials' ability to deliver forces.[15]

In the present study, EC behavior was evaluated weekly over a period of 4 weeks — the interval between patient visits,[4,8,9,12,17] as this time period coincides with the average period when orthodontists usually replace the patient's elastics.[2] The time factor is of paramount importance for ECs, since it is known that one of their main properties, i.e., the dissipation of forces with constant magnitude during their clinical application, is directly influenced by the time period during which they are employed, given a loss of tension and consequent force decay.[18] In the present study, a statistically significant difference was noted between the mean deformation of the first week and the others (Table 7), which suggests - without considering the biology of tooth movement – that it is convenient to change ECs weekly, since comparisons between the second and third weeks, between the third and fourth weeks, and between the second and fourth weeks, showed no significant differences. However, it is recommended that ECs be replaced every 3 weeks.[6,13] Furthermore, ECs should not be used for longer than 4 weeks, not only due to force decay but also due to difficulties in oral cleaning, with the resulting accumulation of food debris.[13] Additionally, EC use should not exceed a period of 6 weeks as ECs eventually lose, on average, 30% of their initial force. Besides, there is an increase in the accumulation of plaque and chemical interaction with food and oral fluids.[11]

Regarding immersion time in artificial saliva, the rate of force decay increases with time,[1,9,24] as concluded in this study. Although not significant statistically, a reversal was also observed between the means of the second and third weeks (Table 5 and Fig 5).

As regards the degree of elongation undergone by ECs, force decay is proportional to the degree of stretching to which the ECs are subjected,[1] in agreement with the findings of this study (Table 5 and Fig 4). For example, it became evident that, as shown in Table 1, 10% stretching yielded a mean deformation of approximately 8.4%, whereas 100% stretching caused the deformation to increase to 56.6%. Thus, from a clinical standpoint, an issue could be raised: How much stretching is recommended to (a) achieve a low rate of permanent deformation, and (b) apply forces that are as constant as possible? Based on the results of this study, it would be reasonable to suggest 30% stretching, which would provide a mean deformation of about 17.9%. However, it should be emphasized that this argument is only applicable to 3M Unitek ECs which were analyzed here, since ECs can vary in thickness, elastic property, manufacturing process, adding pigments or fluorine and distance between modules. These factors, acting alone or in conjunction, will certainly influence both the forces delivered and the degree of permanent deformation undergone by these materials. Therefore, professionals who use ECs should be aware of the various issues and types of materials addressed in this study, and act accordingly.

The use of a tension gauge is advised to measure the initial force since certain closed chains — when stretched to 100% of their original length — can produce excessive forces, approaching 450 grams. It is therefore recommended to stretch these ECs between 50% and 75% of their original length. However, there are ECs which, when stretched to 100% of their original length, produce acceptable magnitudes of force (approximately 300 grams).[3] Based on this, professionals are advised to stock in their offices

ECs with at least three different distances between modules, provided they have the same thickness and are manufactured by the same company. This would allow the application of the desired force magnitude, taking into consideration the degree of stretching recommended by this study (30%).

Furthermore, a permanent deformation of 50% to 60% was observed when the ECs were stretched to 100% of their original length. These percentages resemble those found for American Orthodontics (54%) ECs.[15] However, the percentages found for 3M Unitek (76%) ECs[15] differ from those found in this study.

While a simulation was made of the oral environment, it should be stressed that in an *in vivo* study, a wide range of factors such as the patient's diet, the composition of their saliva, presence of bacterial enzymes, masticatory forces, tooth movement, distance of force application, presence of fluoride and temperature changes could affect the mechanical performance of ECs, thereby altering the results obtained in this study.

CONCLUSION

Based on the results it can be conclude that:

1) A direct relationship was found between degree of stretching and permanent deformation of the ECs evaluated.

2) The mean stretching percentages found were 8.4% to 10%, exceeding 20% (21.3%) when stretched by 40%, and reaching 56.6% permanent deformation when stretched to 100% of their original length.

3) The highest percentage of permanent deformation occurred during the first week, and was not statistically significant after this period.

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