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Effect of citric acid on force decay of orthodontic elastomeric chains

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ABSTRACT

Background: This study aimed to assess the effect of citric acid, as a weak acid commonly used in food industry, on elastomeric chain force decay.

Materials and Methods: In this *in vitro*, experimental study, sixty elastomeric chains from two commercial brands of American Orthodontics and Ortho Technology ($n = 30$) were cut into five-piece segments. Elastomeric chains of each brand were randomly divided into two groups of control (artificial saliva) and citric acid. All elastomeric chains were incubated in artificial saliva at 37°C. Experimental samples were immersed in 10 mL of citric acid for 90 s daily and were then transferred back to the artificial saliva. The elastomeric chain force was measured at baseline (before the experiment), 1 day, 1 week, 2 weeks, and 3 weeks using an electromechanical universal testing machine. Data were analyzed using *t*-test, Kruskal–Wallis test, and Mann–Whitney U-test at 0.05 level of significance.

Results: The elastomeric chain force gradually degraded over time. The difference in this respect was not significant at 2 and 3 weeks in any group ($P > 0.05$). On initiation of the experiment, the force in the citric acid group experienced a greater decay than that in the control group; the difference between the citric acid and control groups in both the brands was significant at all time points until the end of the 3rd week ($P < 0.05$). The difference between the American Orthodontics and Ortho Technology brands in the control and citric acid groups was significant at all time points ($P < 0.001$).

Conclusion: Elastomeric chains in both the citric acid and artificial saliva groups experienced force decay over time. Force decay was greater in the citric acid group. Thus, citric acid can effectively decrease the elastomeric chain force. The Ortho Technology chain force was higher than that of American Orthodontics in both the groups at all time points.

Key Words: Biodegradation, citric acid, elastomeric

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INTRODUCTION

Elastomeric chains are used in orthodontics for many purposes such as space closure.[1] They are extensively used due to low cost, being hygienic and easy application.[2,3] Despite the advantages of elastomeric chains, their properties are often affected by heat and moisture.[4] The main drawback of elastomeric chains is their force decay due to the breakage of cross-links between the long-chain molecules during clinical application.[5]

It has been reported that elastomeric chains lose a great portion of their force (around 50%–70%) within the first 24 h of use, and this force decay continues at a slower pace in the next 3–4 weeks and can be influenced by a number of factors.[6-8] Rapid force

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decay in elastomeric chains results in inadequate tooth movement, necessitating additional appointments for activation of the appliance.[9]

The level of elastomeric chain force depends on several factors such as the materials used by the manufacturer for their fabrication, dyes added to the chains, form of the chain (open or closed), being subjected to tension before use, sterilization techniques, storage techniques,[10] environmental factors such as tooth movement, thermal alterations, acidity of the environment, use of mouthwashes, salivary enzymes, and masticatory forces. The abovementioned factors can all affect the trend of force decay and relaxation behavior of elastomeric chains.[5]

Oral cavity has a complex environment, and orthodontic appliances in the oral cavity are subjected to thermal, chemical, and mechanical alterations over long periods of time, which may result in their degradation.[11] The effect of environmental factors on the pattern of force decay of elastomeric chains has been previously evaluated.[12,13] Salivary enzymes and masticatory forces change the properties of elastomeric chains.[14,15] The effect of different environmental factors such as pH and thermal alterations and the effects of commonly consumed drinks on the properties of elastomeric materials have also been studied.[16-19]

Citric acid is a naturally occurring weak organic acid found in all citrus fruits and vegetables.[20] It is used widely as an acidulant and pH regulator. Furthermore, it is added to foods and drinks as a flavor enhancer, preservative and antioxidant synergist.[21] It has been approved by the FAO/WHO as a safe additive and is, therefore, extensively used in the food industry.[22]

This *in vitro* study aimed to assess the effect of citric acid on elastomeric chain force decay. In case of finding a positive effect, orthodontic patients should be advised to decrease the consumption of products containing citric acid.

MATERIALS AND METHODS

In this *in vitro*, experimental study, a total of 60 short elastomeric chains from two major manufacturers, namely American Orthodontics (Sheboygan, Wisconsin, USA) and Ortho Technology (Tampa, Florida, USA) were selected (n = 30 from each brand). They were then cut into five-piece segments. To prevent possible damage to the chains during the process of cutting, the sections were made at the center of adjacent links at the two ends of the five-piece segments such that at each end of the five-piece segment, a half-link was present [Figure 1a]. The segments from each brand were then randomly divided into two groups of control (artificial saliva) and citric acid. Thus, the following four groups were evaluated in this study:

- Group 1: American Orthodontics chains immersed in artificial saliva
- Group 2: American Orthodontics chains immersed in citric acid
- Group 3: Ortho Technology chains immersed in artificial saliva
- Group 4: Ortho Technology chains immersed in citric acid.

To simulate the oral environment, all samples were immersed in artificial saliva (Hypozalix, Biocodex, France) and incubated at 37°C. The composition of artificial saliva included water, $MgCl_2$, NaCl, and cellulose materials with a pH of 7.2 and 110 cps viscosity. Aqueous solution of 0.001 M citric acid with a pH of 2.3 was used to simulate acidic conditions. This solution is commonly used as an external acid in laboratory models of dental erosion. The samples were immersed in 10 mL of citric acid solution for 90 s and were then transferred back to artificial saliva.

The details of the procedure in the two groups were as follows:

- Groups 1 and 3 (control group): Elastomeric chains in these two groups were only immersed in artificial saliva and incubated at 37°C

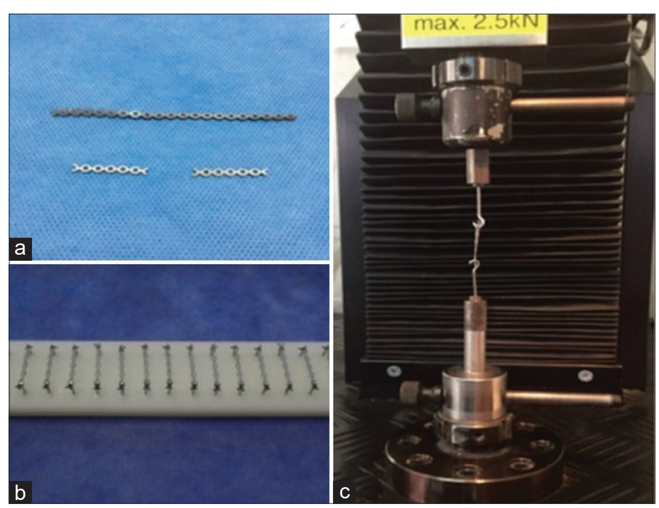

Figure 1: (a and b) Chains connected to the fixtures. (c) Electromechanical universal testing machine for measurement of chain force.

- Groups 2 and 4 (citric acid): Elastomeric chains in these two groups were removed from the artificial saliva on a daily basis and immersed in citric acid solution for 90 s. After removal from the citric acid solution, they were transferred back to the artificial saliva.

To measure the magnitude of force generated by the chains, two stainless steel metal fixtures were mounted in self-cure acrylic resin [Figure 1b]. The diameter of the fixtures was 1.2 mm and the distance between the two fixtures was 25 mm to simulate the distance between the hook of a first molar and the distal wing of a canine tooth bracket in the clinical setting. In this distance, chains apply 100–300 g force, which is suitable for canine tooth retraction. The chains were positioned between the two fixtures.

The force generated by the chains was measured at five time points, namely at baseline (before the experiment), 1 day, 1 week, 2 weeks, and 3 weeks using an electromechanical universal testing machine (K-21046, Switzerland) [Figure 1c] and reported in Newtons (N). The study period was 3 weeks. Orthodontic appointments are often scheduled every 3 or 4 weeks to replace the elastomeric chains. Thus, some studies evaluated the behavior of these materials for a period of 21 days.[23-25]

All measurements were made at room temperature. Forceps designed for this purpose was used to transfer the elastomeric chain between the fixtures to the universal testing machine. The forceps would open by 25 mm so that all samples received a similar level of tension. The machine had two major probes. The study probes were mounted on the two major probes of the machine after being designed and manufactured. The minor probes were opened by 25 mm (corresponding to the distance between the two fixtures), and the force generated by the chain was displayed on the monitor. Considering the variations and alterations in force during the first few seconds of mounting of chains on the machine, a 10-s time period was allowed after mounting of the chains on the probes and then the force was measured.

The *t*-test was used to compare the two brands and the citric acid and artificial saliva groups. The Kruskal–Wallis test and the Mann–Whitney U-test were applied for the comparison of different time points. $P < 0.05$ was considered statistically significant.

RESULTS

As shown in Figure 2, elastomeric chain force gradually degraded in all the groups during the 3 weeks such that the difference in force in all the groups between baseline and 24 h and 1 week and 2 weeks was significant ($P < 0.001$). The difference in force measured at 2 and 3 weeks was not significant in any group ($P > 0.05$).

As shown in Table 1, no significant difference was noted in force between the two groups of control and citric acid in any of the two brands ($P > 0.05$). After initiating the experiment, the force in the citric acid group experienced greater decay compared with the control group, and the difference in this

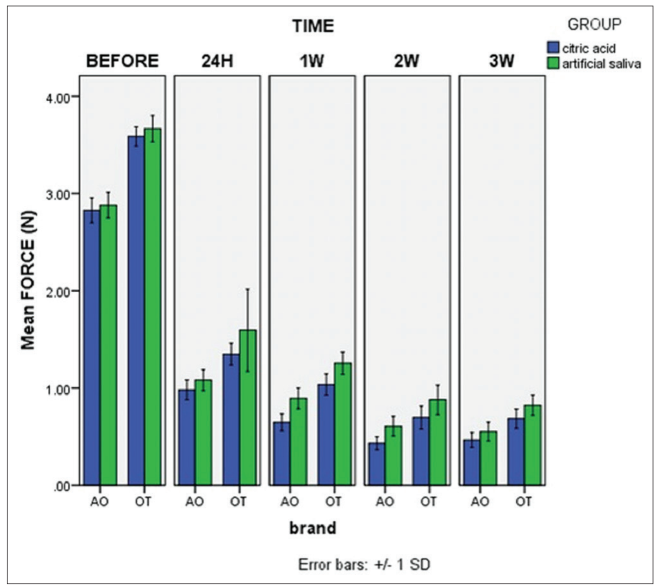

Figure 2: American Orthodontics and Ortho Technology elastomeric chain force in the artificial saliva and citric acid groups.

Table 1: Comparison of American Orthodontics and Ortho Technology elastomeric chain force in the control and citric acid groups at different time points

Time	Brand	*P*
Baseline	AO	0.271
	OT	0.074
24 h	AO	0.014
	OT	0.38
1 week	AO	0.000
	OT	0.000
2 weeks	AO	0.000
	OT	0.001
3 weeks	AO	0.011
	OT	0.001

AO: American Orthodontics; OT: Ortho Technology respect between the two groups was significant at all time points until the end of the 3rd week in both the brands ($P < 0.05$). The difference between the American Orthodontics and Ortho Technology in the control and citric acid groups was significant at all time points ($P < 0.001$).

The mean elastomeric chain force of the groups measured at five time points is shown in Figure 2 and Table 2.

DISCUSSION

Elastomeric chains are extensively used in orthodontics for tooth movement and space closure. However, their force decay is inevitable.[1] Sensitivity of elastomeric chains to alterations in the oral environment is the most important cause of their plastic deformation and force decay.[25] Acids produced by the oral bacteria and acids present in foods and drinks are important environmental factors that affect the physical and mechanical properties of elastomeric chains.[26] This study aimed to assess the effect of citric acid on elastomeric chain force decay.

The shape and size of elastomeric chains (short, moderate, or long) also affect their mechanical properties.[27] Short chains were evaluated in this study since they retain a higher percentage of force overtime.[28] Furthermore, the chains were cut into five-piece segments; evidence shows that this particular length of a short elastomeric chain provides the required tension for retraction of canine in case of extraction of premolars and is suitable for the 25-mm distance between the canine and first molar teeth.[29]

Force decay tests that are performed at room temperature under dry conditions are weak representatives of oral clinical conditions, and the displayed force values by these tests are different from the actual chain forces in water, artificial saliva, aqueous environments, and distilled water.[30] Thus, in the present study, the samples were immersed in artificial saliva and incubated at 37°C to simulate the clinical setting.

In the present study, the exposure time of chains to acid was 90 s, which corresponds to the time it takes for the pH to drop following the consumption of foods containing citric acid.[31]

In this study, the initial force (10 s) values ranged from 366 ± 13 g to 282 ± 12 g. However, after 24 h, the force levels of all elastic chains ranged from 159 ± 42 g to 98 ± 10 g. This shows a 56%–65% force decay that is in agreement with prior studies that reported 50%–70% force decay after 24 h.[6-8] Such differences are clinically important because 100–300 g forces are clinically acceptable for movement of a group of teeth or a single tooth.[32]

However, the subsequent force decay of the tested chains was more important than the initial force levels. The current results showed that the chain force in all the groups gradually decreased within 3 weeks such that in all the groups, significant differences were noted between the values at baseline, 24 h, 1 week, and 2 weeks. These results were in agreement with the results of previous studies that showed that passage of time was a factor that caused a reduction in chain force.[25,33-35]

Water is known as a factor causing a reduction in elastomeric chain force as well. The reason is the affinity between the hydrogen atoms in the water molecule and oxygen atoms in the chain. This affinity results in water sorption by the polymer chain. The absorbed water creates a space in the polymer chain and expands the gaps. The polymer can absorb water to a certain amount until reaching a peak.[36] In this study, the difference in the magnitude of force at 2 and 3 weeks was not significant in any group, which can be probably due to the fact that water sorption by the chains reached its peak.

At baseline, there was no significant difference in chain force between the control and citric acid groups

Table 2: Mean elastomeric chain force of the four groups measured at five time points

Time	Group, mean force (n)±SD			
	AO in artificial saliva	AO in citric acid	OT in artificial saliva	OT in citric acid
Baseline	2.8800±0.13202	2.8267±0.12799	3.6667±0.13452	3.5867±0.09904
24 h	1.0800±0.10823	0.9800±0.10142	1.5933±0.42337	1.3473±0.11228
1 week	0.8933±0.10728	0.6477±0.08616	1.2547±0.11457	1.0360±0.10966
2 weeks	0.6067±0.10132	0.4327±0.06563	0.8787±0.15156	0.6967±0.11806
3 weeks	0.5520±0.09653	0.4660±0.07500	0.8227±0.10375	0.6853±0.09833

AO: American Orthodontics; OT: Ortho Technology; SD: Standard deviation in any brand. After initiation of the experiment, the magnitude of force in the citric acid group experienced a greater reduction compared with that in the control group, and the difference between the two groups was significant in both the brands at all time points until the end of the 3-week study period. This finding indicates that citric acid can effectively decrease the elastomeric chain force. This finding was in agreement with the result of Nattrass *et al*., who suggested that acidity can cause force decay.[37] However, our result in this respect was in contrast to those of Suprayugo *et al*., Santos *et al*., and Teixeira *et al*., who believed that acidity cannot effectively decrease elastomeric chain force.[17,24,38] Furthermore, this result was in contrast to the findings of Ferriter *et al*. and Pithon *et al*., who reported a smaller reduction in force of elastomeric chains stored in environments with higher acidity.[34,39] The difference between our results and those of the abovementioned studies can be due to the different environments used in each study. Suprayugo *et al*. and Pithon *et al*. immersed the elastomeric chains in soft drinks, which may contain other additives and compounds. Thus, the results cannot be directly attributed to the acidity of the solutions. Santos *et al*. and Ferriter *et al*. used environments with higher pH than our study. The same results could be obtained in lower pH values.

Elastomeric chains of different brands show variable degrees of reduction in force, which may be attributed to their different manufacturing processes such as printing system, raw materials, additive chemical agents, and shape and size of the loops.[38] In the present study, the magnitude of force of Ortho Technology elastomeric chains in both the control and citric acid groups was significantly higher than the corresponding value in American Orthodontics elastomeric chains at all time points.

It is important to know the magnitude of primary force that elastomeric chains of each manufacturer can retain since knowledge in this respect enables the dental clinicians to initiate treatment with a more suitable magnitude of force that lasts and maintains a minimum desired value until the next appointment session.[10] In this study, the American Orthodontics elastomeric chains immersed in citric acid showed a considerable decrease in the amount of force generated after 24 h. Considering the force value required for orthodontic movement, the American Orthodontics elastomeric chains immersed in citric acid after 24 h, the American Orthodontics elastomeric chains immersed in artificial saliva after 1 week, and the Ortho Technology elastomeric chains immersed in both citric acid and artificial saliva after 2 weeks with remaining force <100 g, lost their effectiveness to close the spaces. Therefore, the Ortho Technology elastomeric chains presented better results in this study.

One of the main limitations in analyzing the results of this study was lack of similar *in vivo* studies. One of the limitations of *in vitro* studies including this one is that the fluctuations of intraoral temperature and acidity due to the consumption of different foods and beverages cannot be simulated *in vitro*. Although *in vitro* studies are valuable, direct generalization of their results to the clinical situations should be performed with caution. Despite these limitations, this study provided the orthodontists with additional information regarding some considerations that need to be taken into account by orthodontic patients such as limiting the consumption of fruits and vegetables containing citric acid during the appliance activation period by the use of elastomeric chains.

CONCLUSION

Elastomeric chains experienced force decay following immersion in artificial saliva and citric acid overtime. After the study onset, the magnitude of force in the citric acid group experienced greater decay, which indicates that citric acid can effectively cause elastomeric force decay. The magnitude of force of Ortho Technology elastomeric chains in both the citric acid and artificial saliva groups was significantly higher than that of American Orthodontics elastomeric chains at all time points.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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