Iran J Orthod. 2022 December; 17(2):e1062. doi:10.22034/IJO.2022.553718.1067.
Published online 2022 December 1 Research Article

# Force Decay of 27 Orthodontic Elastomeric Chains

**Seyed Mohammad Mousavi[1], Sara Mahboubi[1*], Salmeh Kalbassi[2], Vahid Rakhshan[3]**

[1] Assistant Professor, Department of Orthodontics, School of Dentistry, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[2] Orthodontist, Private Practice, Tehran, Iran
[3] Dentist, Private Practice, Tehran, Iran

***Corresponding author:** Sara Mahboubi. Department of Orthodontics, School of Dentistry, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

Email: mahboubi_s@ajums.ac.ir

**Received:** 2022 May 13; **Revised:** 2022 July 24; **Accepted:** 2022 August 1

**Abstract**

**Aim**: The aim of this investigation was to assess the efficacy and force decay of elastomeric chains based on their morphology and elongation extent.
**Methods**: Two-hundred-and-seventy elastics from three companies [Ortho Technology (OT), American Orthodontics (AO), G&H, 10 specimens ×27 subgroups] were elongated to 40%, 60%, and 100% and the initial forces were measured. Then after four weeks of incubation in artificial saliva, the residual forces were measured. Forces and force decays were compared across brands, morphologies, and elongation extents ($\alpha=0.001$).
**Results**: Forces degraded significantly over time (repeated-measures ANOVA, $P<0.001$). Significant differences existed among the levels of all parameters, in terms of the initial forces, residual forces, and force degradation (3-way ANOVA, $P<0.001$). Results of most of the Tukey post hoc tests were significant ($P<0.001$). The longer the elongation extent, the higher the force waste (partial correlation coefficient, $r=0.885$, $P< 0.001$).
**Conclusion**: Initial force was improved when using the OT brand and closed elastics, and by stretching the elastic to 100%. Force loss was minimized when using the G&H brand and open elastics, and by stretching to 40%. Using the OT brand and closed elastics, and 100% stretching caused the highest residual forces after a month. However, the initial forces provided by the 100% elongations were not sound. Force loss was increased by using the OT brand and closed elastics, and with 100% elongations. The lowest residual forces were seen in the AO brand, long elastics, and those elongated to 40%.

*Keywords:* Chain morphology, Elastomeric chains, Force decay, Stretching, Space closure.

## 1. Background

Elastomeric chains are one of the most common, inexpensive, and convenient methods to apply light continuous orthodontic forces, which are preferable to produce dentoskeletal alterations (1-8). They are usually fabricated from polyurethanes and have three morphologies: long (a greater distance between loops), short (a shorter distance between loops), and closed (continuous, in which loops are attached to each other) (1-3,9,10).

Force is time-based and decreases gradually because of chain slippage of adjacent molecules or because their arrangement undergoes permanent deformation facilitated by the mouth environment, temperature, enzymes, or moisture, mastication fatigue, or various beverages and cleansers (1-5,7,9,11-17). As a result, elastomeric chains will lose about half (or even three-fourths) of their initial force in their first day of use, gradually losing the remaining force (5,9,18-21). Therefore, chains that have force losses at a gentler slope, are more desirable because they can exert lighter and more continuous forces and can be better controlled (10).

Despite the clinical importance of elastomeric chains, some major aspects of their force behavior have not been assessed adequately. Two important factors determining the force behavior of elastomeric chains are their morphology and size (5,22,23). Nevertheless, the literature on these factors is scarce and limited to a couple of studies: a small pilot study comparing 10 closed and 10 open chains (24) and a second study in this regard (18). Even more rare is the literature on comparing the different forms of elastics (long, short, and closed)

(10,18) of all three chain morphologies (10).

The second unaddressed issue is: "For a given space, which length of elastomeric chain should be selected?" Of course, a shorter chain can stretch more, exerting a greater force. The extent of initial stretching of chains can be a determinant of (1) their initial force as well as (2) the dynamics of their force degradation (5). Research in this regard has been recently done in which the effects of stretching and chain morphologies and brands on force decay were assessed (10).

Other than that, the only guideline on this is a personal speculation of Andreasen and Bishara (25) who suggested to use chains at a length of one-fourth of the space to obtain an initial elongation of 400%. On the other hand, Rock et al. (26) stated that elongations above 50% might be too much. It is important to note that the terminology "stretching" totally differs from the term "pre-stretching technique", which is a method used to temporarily pre-stretch the elastic chain before use to reduce the tensions in the elastic chain after installation (10).

In light of the broad use and efficacy of elastic chains, and given the scarcity of research on the abovementioned parameters, we aimed to investigate the effects of various factors (stretching extents, morphologies, and brands) on force behavior of elastic chains by reproducing the only similar study in the literature (10), with updated and improved methodology, and by adopting more comprehensive analyses.

## 2. Methods

This in vitro study was performed on 540 observations of 270 elastomeric chains. A total of 90 chain specimens (30 closed chains, 30 short chains, and 30 long chains) were placed into three groups based on brand: Ortho Technology (OT), Lutz, Florida, USA, American Orthodontics (AO), Sheboygan, Wisc, USA, and G&H (GH), Franklin, Indiana, USA. Each of the groups were divided into subgroups: closed, short, and long and then they were divided into lower subgroups of 'elongation extents' (n=10). This was to simulate the extent of stretching of the chain when a shorter or longer chain was selected to close the same space. The stretching extents were 40% (meaning that the chain would be stretched until reaching 140% of its original length), 60%, and 100%.

### *Group classification*

There were three groups of elastic chain brands: AO, OT, and GH (n of each group=90). Each brand was randomly divided into three subgroups of chain shapes: closed, short, and long (n of each subgroup=30). Then each subgroup of chain shapes was randomly divided into three primary subgroups of elongation extents: 40%, 60%, and 100% (n of each primary subgroup=10). We selected these percentages because the stretching extent 100% is suggested by manufacturers for clinical use (5,27) and the stretching extents 40% and 60% were around the 50% extent mentioned by Rock et al. (26). Initial lengths of chains and their length after stretching are presented in Table 1.

Each chain specimen included six middle loops and two marginal loops was used to fix the chain on holder pins.

### *Original force*

The elastic chains were positioned on 30 acrylic plates (10 plates for each brand) and held in place by nine pairs of stainless steel pins (1 mm x 1.5 cm). The chains were kept in this position for four weeks at three different elongation states with each groups securing nine elastic chains at 40%, 60%, and 100% and three chains per elongation (Fig. 1). A digital caliper with a 0.02 mm accuracy (Erste Qualitat, Berlin, Germany) was used to measure the distance between two pins as well as initial lengths of elastic chains. A Mathieu plier was used to fix the chains (10).

A digital force gauge with a measuring accuracy of 0.05% (Lutron FG-20KG, Taipei, Taiwan) was used to measure the force exerted by each chain in Newton. For this purpose, the chain was removed from one end and attached into the gauge hook at the same distance it was originally placed on pins.

**Table 1.** Lengths of elastic chains at different elongation extents (mm)

| | **Ortho Technology** | | | **American Orthodontics** | | | **G&H** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Stretch** | Closed | Short | Long | Closed | Short | Long | Closed | Short | Long |
| **Initial** | 20.11 | 23.32 | 28.98 | 21.34 | 28.21 | 31.17 | 20.87 | 26.12 | 30.23 |
| **40%** | 28.15 | 32.65 | 40.57 | 29.88 | 39.49 | 43.64 | 29.22 | 36.57 | 42.32 |
| **60%** | 32.18 | 37.31 | 46.37 | 34.14 | 45.14 | 49.87 | 33.39 | 41.79 | 48.37 |
| **100%** | 40.22 | 46.64 | 57.96 | 42.68 | 56.42 | 62.34 | 41.74 | 52.24 | 60.46 |

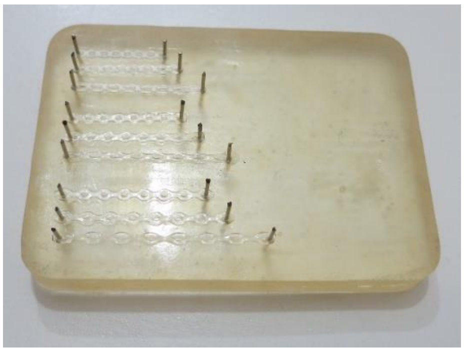

**Figure 1.** One of the plates with elastic chains and pins

### *Incubation*

The same chains with their plates were submersed in stainless steel containers with artificial saliva (RGS, Tehran, Iran). Afterward, the sealed boxes were incubated for four weeks (Sina, Tehran, Iran) in an incubator furnished with a shaker. The incubator contained water at 37 ± 1°C below the box leads.

### *Residual force and force decay*

Incubated elastic chains were assessed again with the force gauge to measure the residual (post-incubation) force. The difference between original and residual forces were regarded as force decay.

### *Statistical analyses*

Descriptive statistics were computed. Data normality was examined using histograms and the Shapiro-Wilk test. The repeated-measures 3-way analysis of variance (ANOVA) and Tukey post hoc tests assessed changes of force over time. The independent-samples 3-way ANOVA and Tukey were used to compare forces of different chain brands and types under different elongations, initial forces, force decays, and residual (post-incubation) forces. The one-way ANOVA was used to compare initial forces and percentages of force loss among the levels of the different parameters. The correlation between the extent of stretching with all forces were assessed using a partial correlation coefficient from the software SPSS version 25 (IBM, Armonk, NY, USA). The level of significance was predetermined as 0.001.

## 3. Results

The average of all chain forces decreased from an initial mean force of 407.4±135.5 g to 109.3±28.8 g. The force decay was therefore 298.2±114.9 g. Descriptive statistics of groups and subgroups are presented in Tables 2 to 6 and Fig. 2 to 4.

**Table 2.** Descriptive statistics pertaining to primary subgroups (n=10) in terms of the original forces, post-incubation forces, and force decays (g)

| Type | Elongation | Force | Ortho Technology | | | | American Orthodontics | | | | G&H | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SD | Min | Max | Mean | SD | Min | Max | Mean | SD | Min | Max |
| Close | 40% | Initial | 268.0 | 14.8 | 250.0 | 300.0 | 338.0 | 23.0 | 300.0 | 370.0 | 350.0 | 27.9 | 300.0 | 380.0 |
| | | Residual | 120.0 | 6.2 | 110.0 | 130.0 | 59.5 | 8.3 | 50.0 | 70.0 | 105.5 | 9.8 | 90.0 | 115.0 |
| | | Decay | 148.0 | 9.5 | 140.0 | 170.0 | 278.5 | 16.3 | 250.0 | 300.0 | 244.5 | 21.0 | 210.0 | 270.0 |
| | 60% | Initial | 484.0 | 9.7 | 470.0 | 500.0 | 429.0 | 24.7 | 390.0 | 460.0 | 439.0 | 49.8 | 370.0 | 500.0 |
| | | Residual | 130.0 | 4.1 | 125.0 | 135.0 | 101.0 | 7.4 | 90.0 | 110.0 | 124.5 | 5.5 | 115.0 | 130.0 |
| | | Decay | 354.0 | 7.4 | 340.0 | 365.0 | 328.0 | 18.7 | 300.0 | 350.0 | 314.5 | 48.2 | 250.0 | 370.0 |
| | 100% | Initial | 672.0 | 19.3 | 650.0 | 700.0 | 596.0 | 15.1 | 560.0 | 610.0 | 612.0 | 21.5 | 590.0 | 650.0 |
| | | Residual | 143.5 | 5.8 | 135.0 | 150.0 | 124.0 | 7.0 | 120.0 | 140.0 | 150.5 | 6.9 | 140.0 | 160.0 |
| | | Decay | 528.5 | 14.2 | 510.0 | 550.0 | 472.0 | 13.2 | 440.0 | 480.0 | 461.5 | 18.3 | 440.0 | 495.0 |
| Short | 40% | Initial | 284.0 | 15.1 | 270.0 | 310.0 | 227.0 | 29.5 | 180.0 | 280.0 | 226.0 | 30.6 | 200.0 | 270.0 |
| | | Residual | 90.0 | 8.2 | 80.0 | 100.0 | 67.0 | 7.1 | 60.0 | 80.0 | 103.5 | 10.0 | 90.0 | 120.0 |
| | | Decay | 194.0 | 8.4 | 180.0 | 210.0 | 160.0 | 23.2 | 120.0 | 200.0 | 122.5 | 23.5 | 100.0 | 160.0 |
| | 60% | Initial | 420.0 | 22.1 | 380.0 | 450.0 | 321.0 | 23.3 | 280.0 | 360.0 | 397.0 | 17.0 | 370.0 | 420.0 |
| | | Residual | 104.0 | 28.0 | 30.0 | 130.0 | 96.0 | 6.6 | 80.0 | 100.0 | 107.0 | 9.5 | 100.0 | 120.0 |
| | | Decay | 316.0 | 38.1 | 280.0 | 420.0 | 225.0 | 18.6 | 200.0 | 260.0 | 290.0 | 10.5 | 270.0 | 300.0 |
| | 100% | Initial | 603.0 | 28.7 | 570.0 | 650.0 | 479.0 | 22.8 | 440.0 | 500.0 | 500.0 | 22.1 | 470.0 | 550.0 |
| | | Residual | 164.0 | 5.2 | 160.0 | 170.0 | 119.0 | 5.2 | 110.0 | 125.0 | 127.5 | 5.9 | 120.0 | 135.0 |
| | | Decay | 439.0 | 24.7 | 410.0 | 480.0 | 360.0 | 20.1 | 320.0 | 380.0 | 372.5 | 17.4 | 350.0 | 415.0 |
| Long | 40% | Initial | 260.0 | 27.1 | 200.0 | 300.0 | 257.0 | 32.3 | 210.0 | 300.0 | 210.0 | 18.9 | 180.0 | 240.0 |
| | | Residual | 102.0 | 9.2 | 90.0 | 110.0 | 72.0 | 7.5 | 60.0 | 80.0 | 50.0 | 7.1 | 40.0 | 60.0 |
| | | Decay | 158.0 | 20.4 | 110.0 | 190.0 | 185.0 | 25.4 | 150.0 | 220.0 | 160.0 | 13.1 | 140.0 | 180.0 |
| | 60% | Initial | 393.0 | 12.5 | 380.0 | 420.0 | 394.0 | 7.0 | 380.0 | 400.0 | 324.0 | 26.3 | 270.0 | 350.0 |
| | | Residual | 123.5 | 8.8 | 110.0 | 135.0 | 84.0 | 5.7 | 75.0 | 90.0 | 113.0 | 10.6 | 100.0 | 130.0 |
| | | Decay | 269.5 | 6.9 | 260.0 | 285.0 | 310.0 | 2.4 | 305.0 | 315.0 | 211.0 | 19.7 | 170.0 | 230.0 |
| | 100% | Initial | 662.0 | 31.9 | 600.0 | 700.0 | 441.0 | 32.1 | 400.0 | 490.0 | 415.0 | 11.8 | 400.0 | 430.0 |
| | | Residual | 150.5 | 6.4 | 140.0 | 160.0 | 91.5 | 7.5 | 80.0 | 100.0 | 127.5 | 5.9 | 120.0 | 135.0 |
| | | Decay | 511.5 | 25.9 | 460.0 | 545.0 | 349.5 | 25.2 | 320.0 | 390.0 | 287.5 | 8.9 | 270.0 | 300.0 |

SD=standard deviation; Min=minimum; Max=maximum.

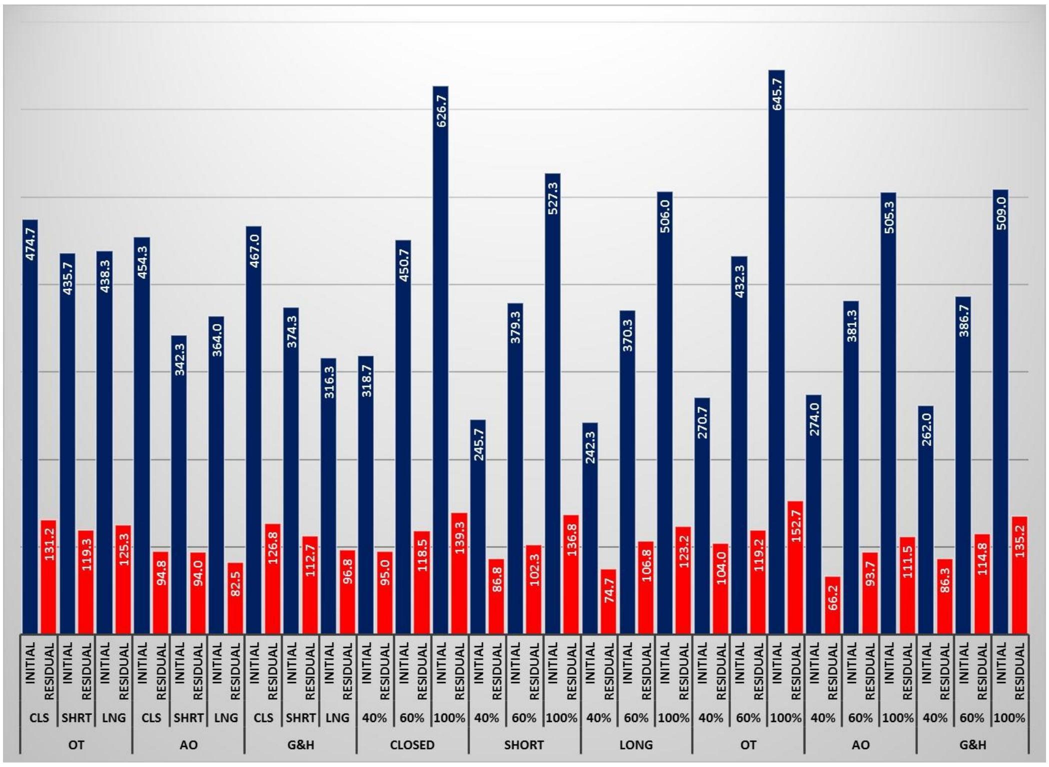


**Figure 2.** Mean values pertaining to pre- and post-incubation forces (g) in different subgroups (n=30 per bar). OT=Ortho Technology; AO=American Orthodontics

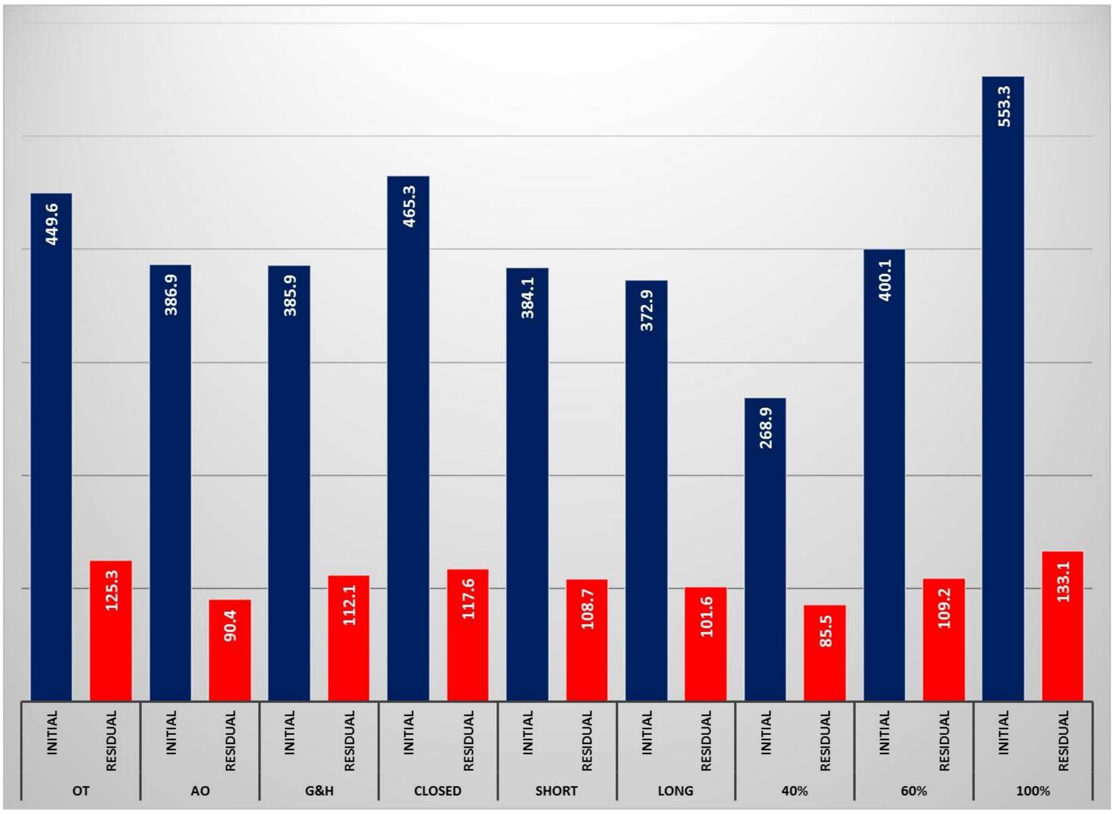


**Figure 3.** Mean values pertaining to pre- and post-incubation forces (g) in different groups (n=90 per bar). OT=Ortho Technology; AO=American Orthodontics

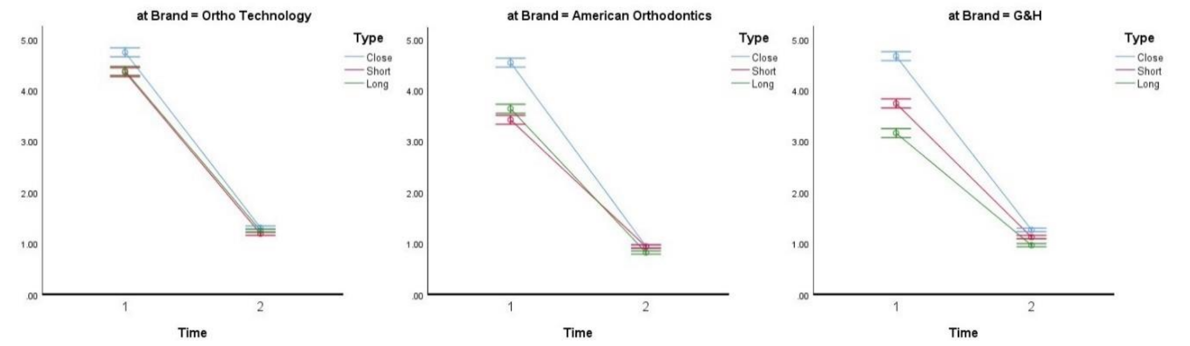


**Figure 4.** Marginal means and 95% confidence intervals for all chain forces for the different morphologies and brands, but irrespective of the elongation factor (1 Newton=100 g)

***Force decay***

The 3-way repeated-measures ANOVA showed a highly significant decline in the force (P<0.001). Effects of stretching extent (P<0.001), brands (P<0.001), and chain types (P<0.001) were also significant as well as all interactions (all 11 P values<0.001). All Tukey pairwise comparisons were also significant (all 9 P values<0.001).

***Factors affecting the forces and force decay***

***Initial forces***

According to the 3-way independent-samples ANOVA (n=270), differences existed among chain types (P<0.001), among brands (P<0.001), and among the elongated lengths (P< 0.001) in terms of initial force. Interactions were as well significant (all P values<0.001). The Tukey post hoc test results were mostly significant: OT had higher initial forces than both AO and GH, while AO and GH had almost similar initial forces. Closed chains had higher initial forces compared to both short and long chains; the smallest initial force belonged to long chains. The stretching extents 100% and 40% caused the highest and lowest initial forces, respectively (Table 7).

***Force decay***

The result of the 3-way ANOVA test pertaining to force decays were also all significant: among chain types (P<0.001), brands (P<0.001), and the three elongated lengths (P<0.001) with significant interactions (all P values<0.001). Most of the Tukey post hoc comparisons were significant: OT and GH had the highest and lowest extents of force decay, respectively. Closed chains had greater force decays compared to the short and long chains, but force decay extents of the long and short chains were almost similar. Elongations for 100% and 40% resulted in the highest and lowest force decays, respectively (Table 7).

***Residual forces***

Similarly, post-incubation (residual) forces were as well significantly different among brands, types, and elongations (all 3-way ANOVA's P values < 0.001). Their interactions were also significant (all P values<0.001). All Tukey test results were significant: OT and AO had the highest and lowest residual (post-incubation) forces, respectively. Closed and long chains had the highest and lowest residual forces, respectively. The highest and lowest remaining forces belonged to the elongated extents 100% and 40%, respectively (Table 7).

***Subgroup analyses***

***In each morphology***

According to the one-way ANOVA test, initial forces induced by the three brands were not significant in the case of close and short chains, but the difference was significant for the long chains (Table 3) with OT having the highest initial force.

Moreover, percentages of force loss were different between the three brands in the closed chains and in the long chains (Table 3). In the closed chains, OT had the smallest percent of force decay and similarly, in the long chains, OT had the smallest force decay percentage.

***Under each stretching extent***

When stretched for 40%, the initial force was not significantly different among the different brands, but it differed among brands when the chain was stretched for 60% and 100% (Table 4). In both cases, OT had the highest initial force. Significant differences existed among brands regarding force decay irrespective of elongation length (Table 4). In the 40% elongation, OT had the minimum force decay; however, in the other two elongations, G&H had the minimum force decay.

***In each brand, across the morphologies***

The initial forces differed between the three morphologies in the AO and G&H brands (Table 5). In the case of the OT brand, the force decay was not significantly different among the three morphologies. However, there were differences among chain morphologies in the case of the other two brands (Table 5). In both cases, short chains caused the least extent of force decay.

**Table 3.** Initial forces (g) and extents of force decay (% of initial force) in different levels of subgroups (n=30) and groups (n=90). The P value was calculated using the one-way ANOVA test among brands

| Parameters | | | N | Mean | SD | Minimum | Maximum | P |
|---|---|---|---|---|---|---|---|---|
| Close | Original (g) | Ortho Technology | 30 | 474.7 | 168.5 | 250.0 | 700.0 | 0.839 |
| | | American Orthodontics | 30 | 454.3 | 110.6 | 300.0 | 610.0 | |
| | | G&H | 30 | 467.0 | 115.7 | 300.0 | 650.0 | |
| | | Total | 90 | 465.3 | 132.9 | 250.0 | 700.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 69.0 | 10.2 | 53.7 | 79.2 | < 0.001 |
| | | American Orthodontics | 30 | 79.4 | 2.7 | 75.6 | 84.8 | |
| | | G&H | 30 | 72.2 | 3.1 | 67.1 | 76.7 | |
| | | Total | 90 | 73.5 | 7.7 | 53.7 | 84.8 | |
| Short | Original (g) | Ortho Technology | 30 | 435.7 | 134.7 | 270.0 | 650.0 | 0.012 |
| | | American Orthodontics | 30 | 342.3 | 108.6 | 180.0 | 500.0 | |
| | | G&H | 30 | 374.3 | 117.2 | 200.0 | 550.0 | |
| | | Total | 90 | 384.1 | 125.5 | 180.0 | 650.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 72.1 | 4.7 | 66.7 | 93.3 | 0.006 |
| | | American Orthodontics | 30 | 71.9 | 2.7 | 66.7 | 76.6 | |
| | | G&H | 30 | 67.2 | 9.8 | 50.0 | 75.5 | |
| | | Total | 90 | 70.4 | 6.8 | 50.0 | 93.3 | |
| Long | Original (g) | Ortho Technology | 30 | 438.3 | 171.8 | 200.0 | 700.0 | 0.001 |
| | | American Orthodontics | 30 | 364.0 | 83.4 | 210.0 | 490.0 | |
| | | G&H | 30 | 316.3 | 87.4 | 180.0 | 430.0 | |
| | | Total | 90 | 372.9 | 130.1 | 180.0 | 700.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 68.8 | 7.1 | 55.0 | 77.9 | < 0.001 |
| | | American Orthodontics | 30 | 76.6 | 3.5 | 69.6 | 80.3 | |
| | | G&H | 30 | 70.2 | 5.0 | 61.8 | 80.0 | |
| | | Total | 90 | 71.9 | 6.4 | 55.0 | 80.3 | |

**Table 4.** Initial forces (g) and extents of force decay (% of initial force) in different subgroups and groups. The P value is calculated using the one-way ANOVA test among brands

| Parameters | | | N | Mean | SD | Minimum | Maximum | P |
|---|---|---|---|---|---|---|---|---|
| 40% | Original (g) | Ortho Technology | 30 | 270.7 | 21.6 | 200.0 | 310.0 | 0.657 |
| | | American Orthodontics | 30 | 274.0 | 55.1 | 180.0 | 370.0 | |
| | | G&H | 30 | 262.0 | 68.5 | 180.0 | 380.0 | |
| | | Total | 90 | 268.9 | 51.9 | 180.0 | 380.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 61.4 | 5.8 | 53.7 | 70.4 | < 0.001 |
| | | American Orthodontics | 30 | 74.9 | 5.7 | 66.7 | 84.8 | |
| | | G&H | 30 | 66.7 | 9.9 | 50.0 | 80.0 | |
| | | Total | 90 | 67.7 | 9.2 | 50.0 | 84.8 | |
| 60% | Original (g) | Ortho Technology | 30 | 432.3 | 41.7 | 380.0 | 500.0 | < 0.001 |
| | | American Orthodontics | 30 | 381.3 | 49.7 | 280.0 | 460.0 | |
| | | G&H | 30 | 386.7 | 58.4 | 270.0 | 500.0 | |
| | | Total | 90 | 400.1 | 54.9 | 270.0 | 500.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 72.3 | 4.7 | 66.7 | 93.3 | < 0.001 |
| | | American Orthodontics | 30 | 75.1 | 3.9 | 67.7 | 80.3 | |
| | | G&H | 30 | 69.8 | 4.2 | 61.8 | 75.5 | |
| | | Total | 90 | 72.4 | 4.7 | 61.8 | 93.3 | |
| 100% | Original (g) | Ortho Technology | 30 | 645.7 | 40.6 | 570.0 | 700.0 | < 0.001 |
| | | American Orthodontics | 30 | 505.3 | 71.1 | 400.0 | 610.0 | |
| | | G&H | 30 | 509.0 | 84.1 | 400.0 | 650.0 | |
| | | Total | 90 | 553.3 | 93.8 | 400.0 | 700.0 | |
| | Force Loss (%) | Ortho Technology | 30 | 76.2 | 2.6 | 71.7 | 79.2 | < 0.001 |
| | | American Orthodontics | 30 | 77.9 | 2.2 | 72.7 | 80.0 | |
| | | G&H | 30 | 73.1 | 2.9 | 67.5 | 76.7 | |
| | | Total | 90 | 75.7 | 3.2 | 67.5 | 80.0 | |

***In each brand, across the stretching extents***

There were significant differences between initial forces caused by stretching the chains for 40%, 60%, or 100% regardless of the brand (Table 6) and 100% elongation caused the highest initial force regardless of the brand.

The difference between force decays of the different stretching extents was as well significant regardless of the brand (Table 6) and the lowest force decay belonged to 40% elongation.

**Table 5.** Initial forces (g) and extents of force decay (% of initial force) in different subgroups and groups. The P value is calculated using one-way ANOVA test among different morphologies

| Parameters | | | N | Mean | SD | Minimum | Maximum | P |
|---|---|---|---|---|---|---|---|---|
| Ortho Technology | Original (g) | Close | 30 | 474.7 | 168.5 | 250.0 | 700.0 | 0.572 |
| | | Short | 30 | 435.7 | 134.7 | 270.0 | 650.0 | |
| | | Long | 30 | 438.3 | 171.8 | 200.0 | 700.0 | |
| | | Total | 90 | 449.6 | 158.4 | 200.0 | 700.0 | |
| | Force Loss (%) | Close | 30 | 69.0 | 10.2 | 53.7 | 79.2 | 0.187 |
| | | Short | 30 | 72.1 | 4.7 | 66.7 | 93.3 | |
| | | Long | 30 | 68.8 | 7.1 | 55.0 | 77.9 | |
| | | Total | 90 | 70.0 | 7.7 | 53.7 | 93.3 | |
| American Orthodontics | Original (g) | Close | 30 | 454.3 | 110.6 | 300.0 | 610.0 | < 0.001 |
| | | Short | 30 | 342.3 | 108.6 | 180.0 | 500.0 | |
| | | Long | 30 | 364.0 | 83.4 | 210.0 | 490.0 | |
| | | Total | 90 | 386.9 | 111.7 | 180.0 | 610.0 | |
| | Force Loss (%) | Close | 30 | 79.4 | 2.7 | 75.6 | 84.8 | < 0.001 |
| | | Short | 30 | 71.9 | 2.7 | 66.7 | 76.6 | |
| | | Long | 30 | 76.6 | 3.5 | 69.6 | 80.3 | |
| | | Total | 90 | 75.9 | 4.3 | 66.7 | 84.8 | |
| G&H | Original (g) | Close | 30 | 467.0 | 115.7 | 300.0 | 650.0 | < 0.001 |
| | | Short | 30 | 374.3 | 117.2 | 200.0 | 550.0 | |
| | | Long | 30 | 316.3 | 87.4 | 180.0 | 430.0 | |
| | | Total | 90 | 385.9 | 123.4 | 180.0 | 650.0 | |
| | Force Loss (%) | Close | 30 | 72.2 | 3.1 | 67.1 | 76.7 | 0.015 |
| | | Short | 30 | 67.2 | 9.8 | 50.0 | 75.5 | |
| | | Long | 30 | 70.2 | 5.0 | 61.8 | 80.0 | |
| | | Total | 90 | 69.9 | 6.9 | 50.0 | 80.0 | |

**Table 6.** Initial forces (g) and extents of force decay (% of initial force) in different subgroups and groups. The P value is calculated using the one-way ANOVA test among different extents of elongation

| Parameters | | | N | Mean | SD | Minimum | Maximum | P |
|---|---|---|---|---|---|---|---|---|
| Ortho Technology | Original (g) | 40% | 30 | 270.7 | 21.6 | 200.0 | 310.0 | < 0.001 |
| | | 60% | 30 | 432.3 | 41.7 | 380.0 | 500.0 | |
| | | 100% | 30 | 645.7 | 40.6 | 570.0 | 700.0 | |
| | | Total | 90 | 449.6 | 158.4 | 200.0 | 700.0 | |
| | Force Loss (%) | 40% | 30 | 61.4 | 5.8 | 53.7 | 70.4 | < 0.001 |
| | | 60% | 30 | 72.3 | 4.7 | 66.7 | 93.3 | |
| | | 100% | 30 | 76.2 | 2.6 | 71.7 | 79.2 | |
| | | Total | 90 | 70.0 | 7.7 | 53.7 | 93.3 | |
| American Orthodontics | Original (g) | 40% | 30 | 274.0 | 55.1 | 180.0 | 370.0 | < 0.001 |
| | | 60% | 30 | 381.3 | 49.7 | 280.0 | 460.0 | |
| | | 100% | 30 | 505.3 | 71.1 | 400.0 | 610.0 | |
| | | Total | 90 | 386.9 | 111.7 | 180.0 | 610.0 | |
| | Force Loss (%) | 40% | 30 | 74.9 | 5.7 | 66.7 | 84.8 | 0.011 |
| | | 60% | 30 | 75.1 | 3.9 | 67.7 | 80.3 | |
| | | 100% | 30 | 77.9 | 2.2 | 72.7 | 80.0 | |
| | | Total | 90 | 75.9 | 4.3 | 66.7 | 84.8 | |
| G&H | Original (g) | 40% | 30 | 262.0 | 68.5 | 180.0 | 380.0 | < 0.001 |
| | | 60% | 30 | 386.7 | 58.4 | 270.0 | 500.0 | |
| | | 100% | 30 | 509.0 | 84.1 | 400.0 | 650.0 | |
| | | Total | 90 | 385.9 | 123.4 | 180.0 | 650.0 | |
| | Force Loss (%) | 40% | 30 | 66.7 | 9.9 | 50.0 | 80.0 | 0.001 |
| | | 60% | 30 | 69.8 | 4.2 | 61.8 | 75.5 | |
| | | 100% | 30 | 73.1 | 2.9 | 67.5 | 76.7 | |
| | | Total | 90 | 69.9 | 6.9 | 50.0 | 80.0 | |

**Table 7.** Tukey test results, comparing forces (g) between pairs within different parameters

| Variable | Compared pairs | | Initial Force | | Force Decay | | Residual Force | |
|---|---|---|---|---|---|---|---|---|
| | | | Diff | P | Diff | P | Diff | P |
| Brand | OT | AO | 62.7 | < 0.001 | 27.8 | < 0.001 | 34.8 | < 0.001 |
| | | G&H | 63.7 | < 0.001 | 50.5 | < 0.001 | 13.2 | < 0.001 |
| | AO | G&H | 1.0 | 0.959 | 22.7 | < 0.001 | -21.7 | < 0.001 |
| Chain Type | Closed | Short | 81.2 | < 0.001 | 72.3 | < 0.001 | 8.9 | < 0.001 |
| | | Long | 92.4 | < 0.001 | 76.4 | < 0.001 | 16.1 | < 0.001 |
| | Short | Long | 11.2 | 0.007 | 4.1 | 0.382 | 7.1 | < 0.001 |
| Elongation | 40% | 60% | -131.2 | < 0.001 | -107.5 | < 0.001 | -23.7 | < 0.001 |
| | | 100% | -284.4 | < 0.001 | -236.8 | < 0.001 | -47.6 | < 0.001 |
| | 60% | 100% | -153.2 | < 0.001 | -129.3 | < 0.001 | -23.9 | < 0.001 |

OT=Ortho Technology; AO=American Orthodontics; Diff=difference in forces of the compared pair

***Correlations***

A strong positive correlation existed between force decay and elongation extents (r=0.885, P<0.001, partial correlation coefficient) for elastic types and brands.

**4. Discussion**

Our findings successfully reproduced a considerable part of the previous study (10) although we also assessed and analyzed aspects that were not covered by it. We used the same brands as in the previous study because generalization of brands to each other is not recommended and because the GH brand was not assessed in the literature except only in that study, making the investigation of that brand desirable. In the current study, the initial force benefited from using the OT brand and closed chains, and by elongating the elastics for 100%. On the other hand, the least desirable results in terms of the initial force were obtained by the AO and GH brands and long elastics, and stretching the elastic for 40%. In this study, based on the three specific elastic bands tested, usage of OT elastics, closed chains, and elongating the elastic for 100% improved the initial force. On the other hand, using AO and GH brands and long elastics, and stretching the elastics for 40% yielded the lowest initial forces. Using GH elastics and open elastics (long and short chains), and stretching the chain for 40% minimized the force decay, while utilizing OT chains and closed elastics, and stretching the chain for 100% maximized the force loss. The force decay was highly correlated with the stretching extents and this was in line with the only other study examining this issue (10). Therefore, it seems that stretching to a higher degree would increase the force at the expense of a severer force degradation.

The most favorable force loss (the lowest decay) was seen in the case of GH elastics, open elastics (long and short), and stretching the chain for 40%. On the other hand, the worst and highest force degradations were seen in the case of the OT brand, closed elastics, and stretching for 100%. In terms of residual forces, OT had the best results (the highest residual forces), closed chains again showed the best residual forces, and 100% elongation again showed the best residual force. Against these, the AO brand as well as long elastics and 40% elongations showed the lowest residual forces. Moreover, it was demonstrated that longer stretching extents wasted a lot more force over the one-month period of the study. Only two other studies were found in the case of effects of open and closed chains on force: one had discovered that open elastics wasted more force compared to closed ones (18) which was in contrast to our finding. This can be attributed to numerous differing parameters in their study (such as brands). The other one reported no difference between original forces measured in open and closed elastics or between force degradations caused by them (24) and this could mostly be due to their small sample. Our results were in line with the results of the previous study (10).

As detailed above, studied brands and morphologies under various degrees of elongation acted quite differently in terms of the initial and residual forces or their force decay. This can be attributable to dissimilar designs and manufacturing methods and materials (5,9,10,22,23,28,29). The results of the present study showed that 100% elongation exerted excessively severe forces, while higher elongation amounts caused higher force decays and thus, wasted originally desired force. This seems to contradict the speculation of Andreasen and Bishara (25) who had recommended some initial stretching of about 400%, while it was closer to the suggestion of Rock et al (26) who found stretching extents below 50% desirable. It should be noted that since the behavior of different brands vary considerably, one cannot generalize the results of a certain brand to others (as shown in our subgroup analyses). While 40%

stretching could suffice to provide proper forces in a particular brand, the very same elongation extent could fail to keep adequate forces in another brand for a month.

Our findings suggest that all brands and chain morphologies elongation for different extents can provide sufficient initial forces and most of them can retain sufficient residual forces (after a month) to induce bodily dental movements. Still, it seems that elastics stretched for 100% can exert excessively heavy forces in the beginning. Although different clinicians might prefer different extents of force (5, 30), bodily movement of a tooth may need between less than 1 and 3.5 N (between less than 100 and 350 grams) (14, 31-33) and this can be increased to a minimum of 150 g when accounting for friction (5, 6, 10, 34). Therefore, elastic chains that induce lighter forces can be considered clinically acceptable as long as providing the minimum necessary forces.

Our in vitro study had some limitations. In vitro experiments cannot simulate the highly changing environment of the mouth (e.g., food and drinks that are consumed, intermittent masticatory forces, and bacterial plaques). However, at the same time, only in vitro studies can provide controlled conditions to examine the situation and elucidate precise findings about the force kinetics of elastic chains, especially when the design becomes more complicated and involving numerous parameters. We attempted to provide a better partial oral cavity simulation by using artificial saliva. Still, future clinical trials are necessary to examine the forces and properties of such brands of elastic chains in the mouth. Another limitation was the heterogenous results observed for the different groups; it was seen that force behavior of elastic chains heavily depended on brands and morphologies. This observation confirmed the results of previous studies showing a range of various behaviors for different materials (10,35). Therefore, it is not advisable to generalize the results of a certain brand or morphology to others. In other words, it seems that the results of each brand may be generalizable mostly, if not only, to that brand. This calls for examining different morphologies from different brands under various elongation extents in the future. Of course, all these heterogeneous results may become even more complicated in the oral environment, under the influence of various known and unknown factors (such as intermittent masticatory forces of different degrees and directions, bacterial plaque and chemicals released by it, the chemical compounds of foods and drinks, and other parameters); these again warrant more clinical research in this regard.

**Conclusion**

As the most clinically important factor, it was shown that using OT elastics and closed chains, and elongating the chain for 100% retained the highest residual force extents after a month. Whereas, using AO elastics and long chains, and stretching for 40% resulted in the lowest residual forces after a month. It should be noted that the magnitude of force is not the only important factor: The treatment should be physiologic and healthy. In this regard, it appears that elongations as much as about 60% can still provide quite high initial and residual forces without delivering excessively heavy and unhealthy forces in the beginning or after a month; such elongations would as well reduce the extent of force loss to a considerable amount.

**References**

1. Foroughi Moghaddam S, Kamali MD. Force decay and discoloration of thermoplastic and thermoset orthodontic elastomeric chains. Braz Dent Sci. 2022;25(1):1-9. doi: 10.4322/bds.2022.e2612
2. ad Silva Chaves-Filho AC, Costa AR, Sousa Borges LP, Almada Santos EC, Crepaldi MV, Vedovello SAS, et al. Force degradation of elastomeric chains after storage time and mechanical brushing. Braz Dent J. 2021;32(4):55-61. doi: 10.1590/0103-6440202104487. PMID: 34787251.
3. Andhare P, Datana S, Agarwal SS, Chopra SS. Comparison of in vivo and in vitro force decay of elastomeric chains/modules: a systematic review and meta analysis. J World Fed Orthod. 2021;10(4):155-62. doi: 10.1016/j.ejwf.2021.07.003. PMID: 34364839.
4. Menon VV, Madhavan S, Chacko T, Gopalakrishnan S, Jacob J, Parayancode A. Comparative assessment of force decay of the elastomeric chain with the use of various mouth rinses in simulated oral environment: an in vitro study. J Pharm Bioallied Sci. 2019;11(2):S269-S73. doi: 10.4103/JPBS.JPBS_9_19. PMID: 31198351.
5. Mirhashemi A, Saffarshahroudi A, Sodagar A, Atai M. Force-degradation pattern of six different orthodontic elastomeric chains. J Dent (Tehran). 2012;9(4):204-15. PMID: 23323182.
6. Soares Santos AC, Tortamano A, Frazatto Naccarato SR, Dominguez-Rodriguez GC, Vigorito JW. An in vitro comparison of the force decay generated by different commercially available elastomeric chains and NiTi closed coil springs. Braz Oral Res. 2007;21(1):51-7. doi: 10.1590/s1806-83242007000100009. PMID: 17384855.
7. de Carvalho Notaroberto DF, Martins MME, de Andrade Goldner MT, de Moraes Mendes A, Abdo Quintão CC. Force decay evaluation of latex and non-latex orthodontic intraoral elastics: in vivo study. Dental Press J Orthod. 2018;23(6):42-7. doi: 10.1590/2177-6709.23.6.042-047.oar. PMID: 30672984.
8. Ramachandraiah S, Sridharan K, Nishad A, Manjusha KK, Abraham EA, Ramees MM. Force decay

characteristics of commonly used elastomeric chains on exposure to various mouth rinses with different alcohol concentration: an in vitro study. J Contemp Dent Pract. 2017;18(9):813-20. doi: 10.5005/jp-journals-10024-2132. PMID: 28874647.

9. Halimi A, Benyahia H, Doukkali A, Azeroual M-F, Zaoui F. A systematic review of force decay in orthodontic elastomeric power chains. Int Orthod. 2012;10(3): 223-40. doi: 10.1016/j.ortho.2012.06.013. PMID: 22906378.
10. Mousavi SM, Mahboobi S, Rakhshan V. Effects of different stretching extents, morphologies, and brands on initial force and force decay of orthodontic elastomeric chains: An in vitro study. Dent Res J (Isfahan). 2020;17(5):326-37. doi: 10.4103/1735-3327.294331. PMID: 33343840.
11. Braga E, Souza G, Barretto P, Ferraz C, Pithon M. Experimental evaluation of strength degradation of orthodontic chain elastics immersed in hot beverages. J Indian Orthod Soc. 2019;53(4):244–248. doi: 10.1177/0301574219867540.
12. DE Genova DC, McInnes-Ledoux P, Weinberg R, Shaye R. Force degradation of orthodontic elastomeric chains—a product comparison study. Am J Orthod. 1985;87(5):377-84. doi: 10.1016/0002-9416(85) 90197-6. PMID: 3857862.
13. Behnaz M, Namvar F, Sohrabi S, Parishanian M. Effect of bleaching mouthwash on force decay of orthodontic elastomeric chains. J Contemp Dent Pract. 2018;19(2):221-5. doi: 10.5005/jp-journals-10024-2240. PMID: 29422474.
14. Evans KS, Wood CM, Moffitt AH, Colgan JA, Holman JK, Marshall SD, et al. Sixteen-week analysis of unaltered elastomeric chain relating in-vitro force degradation with in-vivo extraction space tooth movement. Am J Orthod Dentofacial Orthop. 2017;151(4):727-34. doi: 10.1016/j.ajodo.2016.10.020. PMID: 28364896.
15. Nachan RA, Kalia A, Al-Shahrani I. Force degradation of orthodontic elastomeric chain due to commonly consumed liquids: An in vitro study. World J Dent. 2015;6(1):31-8. doi: 10.5005/jp-journals-10015-1309.
16. Issa AR, Kadhum AS, Mohammed SA. The effects of zinc-containing mouthwashes on the force degradation of orthodontic elastomeric chains: an in vitro study. Int J Dent. 2022;2022:1-7. doi: 10.1155/2022/3557317. PMID: 35531573.
17. Osorio LB, Osawa Gutierrez LM, de Lima EM, Mota EG, de Menezes LM. Disinfection of orthodontic elastomers and its effects on tensile strength. Turk J Orthod. 2022;35(1):22-6. doi: 10.5152/TurkJ Orthod.2022.20151. PMID: 35370130.
18. Halimi A, Azeroual MF, Doukkali A, El Mabrouk K, Zaoui F. Elastomeric chain force decay in artificial saliva: An in vitro study. Int Orthod. 2013;11(1): 60-70. doi: 10.1016/j.ortho.2012.12.007. PMID: 23375920.
19. Patel A, Thomas B. In vivo evaluation of the force degradation characteristics of four contemporarily used elastomeric chains over a period of 6 weeks. J World Fed Orthod. 2018;7(4):141-5. doi: 10.1016/j.ejwf.2018. 09.001.
20. Adel Qodcieh SM, Al-Khateeb SN, Jaradat ZW, Abu Alhaija ES. Force degradation of orthodontic latex elastics: an in-vivo study. Am J Orthod Dentofacial Orthop. 2017;151(3):507-12. doi: 10.1016/j.ajodo.2016. 08.023.
21. Masoud AI, Tsay TP, BeGole E, Bedran-Russo AK. Force decay evaluation of thermoplastic and thermoset elastomeric chains:A mechanical design comparison. Angle Orthod. 2014;84(6):1026-33. doi: 10.2319/ 010814-28.1. PMID: 24784844.
22. Eliades T, Eliades G, Watts DC. Structural conformation of in vitro and in vivo aged orthodontic elastomeric modules. Eur J Orthod. 1999;21(6):649-58. doi: 10.1093/ejo/21.6.649. PMID: 10665194.
23. Taloumis LJ, Smith TM, Hondrum SO, Lorton L. Force decay and deformation of orthodontic elastomeric ligatures. Am J Orthod Dentofacial Orthop. 1997; 111(1):1-11. doi: 10.1016/s0889-5406(97)70295-6. PMID: 9009917.
24. Eliades T, Gioka C, Zinelis S, Makou M. Study of stress relaxation of orthodontic elastomers: Pilot method report with continuous data collection in real time. Hellenic Orthod Rev. 2003;6(1):13-26.
25. Andreasen GF, Bishara S. Comparison of alastik chains with elastics involved with intra-arch molar to molar forces. Angle Orthod. 1970;40(3):151-8. doi: 10.1043/0003-3219(1970)040<0151:COACWE>2. 0.CO;2. PMID: 5269949.
26. Rock WP, Wilson HJ, Fisher SE. A laboratory investigation of orthodontic elastomeric chains. Br J Orthod. 1985;12(4):202-7. doi: 10.1179/bjo.12.4.202. PMID: 3863676.
27. Dadgar S, Sobouti F, Armin M, Ebrahiminasab P, Moosazadeh M, Rakhshan V. Effects of 6 different chemical treatments on force kinetics of memory elastic chains versus conventional chains: An in vitro study. Int Orthod. 2020;18(2):349-58. doi: 10.1016/j.ortho. 2020.02.003. PMID: 32197834.
28. Eliades T, Eliades G, Silikas N, Watts DC. Tensile properties of orthodontic elastomeric chains. Eur J Orthod. 2004;26(2):157-62. doi: 10.1093/ejo/26.2.157
29. Bousquet JA, Tuesta O, Flores-Mir C. In vivo comparison of force decay between injection molded and die-cut stamped elastomers. Am J Orthod Dentofacial Orthop. 2006;129(3):384-9. doi: 10.1016/j.ajodo.2005.09.002. PMID: 16527634.
30. Nattrass C, Ireland AJ, Sherriff M. An investigation into the placement of force delivery systems and the initial forces applied by clinicians during space closure. Br J Orthod. 1997;24(2):127-31. doi: 10.1093/ortho/ 24.2.127. PMID: 9218110.
31. Baty DL, Volz JE, von Fraunhofer JA. Force delivery properties of colored elastomeric modules. Am J Orthod Dentofacial Orthop. 1994;106(1):40-6. doi: 10.1016/S0889-5406(94)70019-2. PMID: 8017348.
32. Storie DJ, Regennitter F, von Fraunhofer JA. Characteristics of a fluoride-releasing elastomeric chain. Angle Orthod. 1994;64(3):199-209. doi: 10.1043/0003-3219(1994)064<0199:COAFEC>2.0.CO; 2. PMID: 8060016.
33. Boester CH, Johnston LE. A clinical investigation of the concepts of differential and optimal force in canine

retraction. Angle Orthod. 1974;44(2):113-9. doi: 10.1043/0003-3219(1974)044<0113:ACIOTC>2.0.CO;2. PMID: 4597626.

34. Samuels RH, Rudge SJ, Mair LH. A clinical study of space closure with nickel-titanium closed coil springs and an elastic module. Am J Orthod Dentofacial Orthop. 1998;114(1):73-9. doi: 10.1016/s0889-5406(98)70241-0. PMID: 9674684.
35. Aldrees AM, Al-Foraidi SA, Murayshed MS, Almoammar KA. Color stability and force decay of clear orthodontic elastomeric chains: An in vitro study. Int Orthod. 2015;13(3):287-301. doi: 10.1016/j.ortho.2015.06.003. PMID: 26277455.