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Effects of different stretching extents, morphologies, and brands on initial force and force decay of orthodontic elastomeric chains: An *in vitro* study

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ABSTRACT

Background: Elastomeric chains are of clinical importance to orthodontics. Therefore, their behavior should be assessed under different conditions. Some of their critical aspects remain unstudied (including effects of different elongations and chain forms on their force properties). Therefore, we aimed to assess these factors.

Materials and Methods: This *in vitro* study was performed on 540 observations: first, 90 chains (10 specimens per subgroup of three brands [American Orthodontics, Ortho Technology (OT), and G&H], each from three chain types [closed, short, and long]) were stretched for three extents (40%, 60%, and 100%) and their forces were measured using a universal testing machine. Afterward, 270 new chains of the same brands/types were stretched for the same extents by installing them onto pairs of pins with different interpin distances. Plates holding pins/chains were incubated in artificial saliva at 37°C for 4 weeks. Afterward, their forces were measured and analyzed using partial correlation coefficient, three-way analysis of variance (ANOVA), Tukey, Student's *t*, and Mann–Whitney tests ($\alpha = 0.001$).

Results: Forces degraded significantly from an overall mean of 3.97 ± 0.97 N to 1.29 ± 0.39 N after 4 weeks (all $P = 0.000$, *t*-test/Mann–Whitney). ANOVA showed highly significant differences among brands, types, and elongations, in terms of "initial force, force decay, and residual force" (all $P = 0.000$). Almost all *post hoc* pairwise comparisons were significant (Tukey $P = 0.000$). There was a strong positive correlation between elongation extent and force loss ($r = 0.846$, $P = 0.000$).

Conclusion: OT might be the most preferable brand. Closed chains might usually show better results, especially in OT chains. Instead of using chains half of the size of the space (to elongate for 100%), longer chains should be used to stretch for lesser extents.

Key Words: Corrective orthodontics, dental materials, orthodontic space closure

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INTRODUCTION

Orthodontic treatments are based on exerting preferably light and continuous forces in order to induce dentoskeletal changes such as tooth movement. A common, effective, comfortable, and inexpensive method of exerting orthodontic forces is

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using elastomeric chains.[1-6] These products can be used for various tasks such as intramaxillary dental displacements, rotation correction, tooth leveling and aligning, postextraction incisor and canine retraction, midline correction, space closure, orthodontic retention, and traction of impacted teeth, intermaxillary jaw discrepancy corrections, lingual orthodontics, or straight-wire technique.[2,7-10] Elastomeric chains are mainly produced from polyurethanes and come in three types of closed (continuous), open/short, and wide/long.[8]

The force delivered by elastic chains depends on many factors. First, it is time-based: it degrades over time due to various factors such as adjacent molecular chain slippage and permanent deformation, the exposure to the oral cavity with all its temperature/moisture/enzymatic dynamics, mastication, or beverages.[1,2,4,8,11-15] In the 1st day of use, they usually lose about half to three-fourth of their original force, and the degradation continues at a rather steady pace afterward.[2,6,8,10,16,17] Therefore, those chains that can show less decay and retain a greater degree of their overall force can be preferable, as their force would be more controllable and continuous, compared to chains that show a steep decline in time.

Moreover, other factors such as different chemical compositions of chains manufactured by different companies as well as different manufacturing methods might contribute to differences in the level of elastic chains' forces and force decays (although some controversies exist in this regard).[2,8,18-20] In addition, the shape and size of elastic chains might be a determinant of their force.[2,18,21] Closed, short, and long chains are different forms of elastomeric chains. However, almost no study has assessed the behavior of various forms of chains except a very small pilot study comparing 10 closed and 10 open chains[22] and another study comparing closed and open chains.[10]

Another critical parameter determining the initial force of elastic chains as well as their force decay can be the extent at which they are originally elongated.[2] A particular space can be closed by installing different lengths of the same chain brand and type. If a shorter chain is placed, the chain would be stretched for a greater length, thus inserting higher initial forces. On the other hand, a longer length of the same chain can be installed to exert lower initial forces because the chain will be stretched less in such a case. Controversy exists over the subjective opinions of few researchers about the initial elongation of elastic chains. For example, Andreasen and Bishara[23] believed that elastics should be stretched 400% in order to compensate for the later loss of force. Nevertheless, Rock *et al*.[24] asserted that in order to prevent too much forces, elastics should not be stretched beyond 50% of their original length. However, the force exerted by different extents of initial elongation has never been researched *in vitro* or *in vivo*. There are numerous studies on prestretching of elastomeric chains, but prestretching is a completely different concept, in which chains are prestretched before use to relax their stresses, so that force reduction in the mouth becomes slower.[25]

Given the clinical importance of these materials due to their various advantages (such as efficacy, inexpensiveness, and ease of use among others) and their wide use, it is of significant clinical interest to know their force properties as well as factors that can affect their initial force and force decay. In this regard, previous studies have assessed the role of one or two contributing factors each in a limited fashion. Most of them concerned mainly with the pattern and slope of force decay over time.[8] However, some other major clinical aspects remain unaddressed: For example, the initial force and force decay patterns of chains under different elongations are never assessed under different elongation extents (to simulate the closure of a space using different lengths of the same chain). Furthermore, the literature on comparisons between different forms of elastic chains (closed, short, and long) is scarce,[10] especially if all three chain forms are supposed to be compared together. Therefore, we conducted this experimental study to assess simultaneously effects of 9 parameters (3 variables, each with three levels: three brands, three types of chains, and three extents of stretching) on the initial force of elastic chains and their 1-month force decay. We also used a brand which had been assessed only once[10] (G&H, Franklin, Indiana, USA).

MATERIALS AND METHODS

This *in vitro* study was performed on 540 observations of elastomeric chains from three manufacturers (G&H [Franklin, Indiana, USA], Ortho Technology [OT, Lutz, Florida, USA], and American Orthodontics [AO, Sheboygan, Wisconsin, USA]). There were 90 specimens in each brand, divided into three subgroups of morphology (closed, short, and long chains [number of each subgroup = 30 specimens]). Each of these subgroups was divided into three primary subgroups of elongations "40%, 60%, and 100% of the original length" (number of each primary subgroup = 10). The sample size was determined as "10 preincubation + 10 postincubation observations" per the smallest (primary) subgroup. The obtained powers reached >95% in almost all the statistical analyses. All specimens were clear (colorless).

None of the authors have any conflicts of interest, have received any funds from these companies, or are affiliated to them; these brands were selected only because they are commonly used and available in orthodontic practice in Iran.

Specimens

Each specimen was prepared from an as-received elastomeric chain by cutting it (using a ligature cutter) in a way that 8 loops (unit modules) were included in the cut specimen. The two marginal loops would be used to fix the chain on holder pins, without exerting any extra forces to the main 6 loops.

Initial force

Each of the 90 elastomeric chains (10 specimens × 3 brand subgroups × 3 chain type subgroups) was stretched for up to 100% using a universal testing machine (STM-20, Santam, Tehran, Iran), and the magnitude of the original force of each specimen at three different stretching lengths (40%, 60%, and 100%) was recorded in Newton (1 N = 100 g) as the standard international unit of force recommended to use in scientific articles.

Incubation

A total of 30 acrylic plates were produced to hold (during 4 weeks) 270 new elastomeric chains of the three manufacturers (each plate for a brand) stretched at 40%, 60%, and 100% of their original lengths [Figure 1]. Stainless steel pins 1 mm thin and 1.5 cm long fixed on 30 acrylic plates were used to maintain elastic chains on their places. There were 10 plates for each brand, each holding 9 elastic chains at 40%, 60%, and 100% (3 chains per each elongation) using 9 pairs of pins (18 pins per plate). Elastic chains were fixed onto pin pairs, using a Mathieu plier. Afterward, plates were immersed in stainless steel boxes containing artificial saliva (RGS, Tehran, Iran). Sealed containers were then incubated for 4 weeks in an incubator equipped with a shaker (Sina, Tehran, Iran) containing water at 37°C ± 1°C. The level of water in the bath was below container leads.

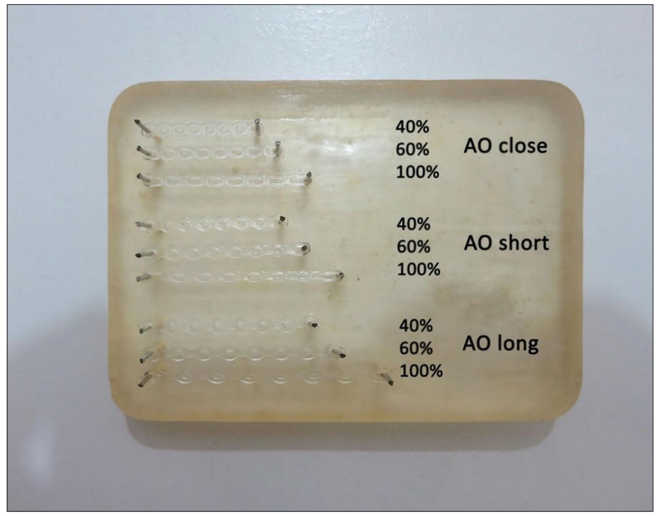

Figure 1: A plate with pins and clear elastic chains mounted on it.

Postincubation force and force decay

After 4 weeks of incubation, elastic chains were again subjected to force measurement using the same universal testing machine. The difference in the forces measured before and after incubation was calculated as force decay.

Statistical analysis

Descriptive statistics were calculated for each subgroup and group. Data in small subgroups were not always normally distributed (Kolmogorov–Smirnov $P < 0.05$). However, in the larger subgroups or groups, the data were treated as normally distributed because of the central limit theorem applied to large samples. Original forces were compared with remaining (postincubation) forces using Mann–Whitney U-test for each of the 27 primary subgroups (n = 10 original forces vs. 10 postincubation forces) and using Student's t-test for the whole data (n = 270 original forces vs. 270 postincubation forces) and for larger (secondary) subgroups (n = 30 original forces vs. 30 postincubation forces per subgroup) and for groups (n = 90 × 2). Comparisons were made using three-way analysis of variance (ANOVA) among forces pertaining to elastic chain types (closed, short, and long), chain brands, and stretching extents (40%, 60%, and 100%) for each of the forces: initial (preincubation), residual (postincubation), and force decay (i.e., the difference between original and postincubation forces). Tukey's *post hoc* test was used for follow-up pairwise comparisons. A partial correlation coefficient was used to estimate the correlation existing between the extent of elongation and force decay, controlling for brand, and type of chains. The software in use was SPSS (version 25, IBM, Armonk, NY, USA). The level of significance was set at 0.001.

RESULTS

The Mann–Whitney U-test showed that the force decreased after incubation in all the 27 primary subgroups [all 27 $P < 0.001$, Table 1]. The decrease was as well significant in all subgroups [$n = 30 \times 2$, all $P < 0.001$, Tables 2-4]. The decrease in the force was again significant in the whole sample or in each of the brands, in each of the stretching extents, or in each of the elastic chain types [all $P < 0.001$, *t*-test, Table 5]. The partial correlation showed that there was a very strong positive correlation between the extent of elongation and the force decay observed after 4 weeks, controlling for chain brands and types ($r = 0.846$, $P = 0.000000$).

The three-way ANOVA ($n = 270$) showed that there were highly significant differences among initial (preincubation) forces pertaining to the three elastic chain brands ($P = 0.000000$), three elastic chain types ($P = 0.000000$), and three elongation lengths ($P = 0.000000$). All interactions were as well significant (all $P = 0.000000$). The Tukey's *post hoc* test showed that each of the pairwise comparisons between each two of chain brands (OT and G&H had the highest and lowest mean initial forces, respectively), between each two of chain types (closed and long chains had the highest and lowest mean initial forces, respectively), and between each two of elongation lengths was significant [100% and 40% stretching levels had, respectively, the highest and lowest mean initial forces, Figure 2 and Table 6].

Evaluating the force decays happened because of incubation, the three-way ANOVA indicated highly significant differences among force decays pertaining to three chain brands ($P = 0.000000$), three chain types ($P = 0.000000$), and three stretching lengths ($P = 0.000000$). All interactions

Table 1: Descriptive statistics pertaining to each of subgroups (*n*=10) in terms of the original forces, postincubation forces, and force decays (N)

Type	Elongation (%)	Force	OT			AO			G&H		
			Mean±SD	Minimum	Maximum	Mean±SD	Minimum	Maximum	Mean±SD	Minimum	Maximum
Closed	40	Original	3.16±0.03	3.11	3.21	3.45±0.07	3.35	3.56	3.30±0.08	3.20	3.45
		Postincubation	1.49±0.10	1.32	1.60	0.92±0.04	0.85	1.00	1.64±0.05	1.60	1.72
		Force decay	1.67±0.08	1.58	1.79	2.53±0.04	2.46	2.60	1.66±0.04	1.60	1.73
	60	Original	4.14±0.04	4.10	4.20	4.45±0.07	4.30	4.52	4.25±0.12	4.00	4.42
		Postincubation	1.81±0.06	1.70	1.90	1.10±0.08	0.93	1.20	1.72±0.03	1.68	1.77
		Force decay	2.33±0.03	2.30	2.40	3.35±0.07	3.22	3.44	2.53±0.10	2.32	2.65
	100	Original	5.39±0.08	5.20	5.47	5.54±0.09	5.40	5.65	5.57±0.10	5.40	5.70
		Postincubation	2.07±0.09	1.98	2.20	1.24±0.08	1.10	1.30	1.97±0.08	1.80	2.10
		Force decay	3.32±0.07	3.22	3.42	4.30±0.10	4.10	4.47	3.60±0.04	3.50	3.63
Short	40	Original	3.04±0.04	3.00	3.10	2.88±0.13	2.70	3.10	2.86±0.11	2.70	3.00
		Postincubation	1.12±0.06	1.06	1.23	0.78±0.07	0.70	0.90	0.76±0.08	0.60	0.88
		Force decay	1.92±0.03	1.87	1.97	2.10±0.07	2.00	2.20	2.10±0.05	2.04	2.20
	60	Original	4.07±0.06	4.00	4.15	3.88±0.18	3.50	4.10	3.45±0.11	3.30	3.64
		Postincubation	1.44±0.06	1.36	1.50	0.92±0.07	0.82	1.00	1.11±0.03	1.08	1.18
		Force decay	2.63±0.03	2.60	2.69	2.97±0.12	2.68	3.10	2.34±0.09	2.22	2.48
	100	Original	5.70±0.11	5.50	5.80	5.00±0.08	4.90	5.15	4.30±0.08	4.18	4.42
		Postincubation	1.77±0.07	1.62	1.82	1.06±0.03	1.00	1.10	1.40±0.02	1.37	1.42
		Force decay	3.93±0.05	3.84	4.01	3.95±0.05	3.86	4.05	2.90±0.06	2.81	3.00
Long	40	Original	3.20±0.15	3.00	3.35	2.89±0.12	2.70	3.00	2.14±0.10	2.00	2.30
		Postincubation	1.25±0.05	1.20	1.30	0.72±0.10	0.60	0.86	1.01±0.02	1.00	1.05
		Force decay	1.95±0.12	1.80	2.11	2.17±0.04	2.08	2.20	1.13±0.08	1.00	1.25
	60	Original	4.17±0.10	4.00	4.25	3.66±0.16	3.40	3.90	2.92±0.14	2.70	3.12
		Postincubation	1.43±0.03	1.40	1.47	0.73±0.07	0.60	0.86	1.42±0.40	1.15	2.00
		Force decay	2.74±0.08	2.60	2.80	2.92±0.10	2.75	3.06	1.50±0.31	0.95	1.82
	100	Original	5.33±0.06	5.20	5.40	4.47±0.10	4.30	4.60	4.00±0.13	3.80	4.20
		Postincubation	1.53±0.03	1.48	1.58	1.07±0.08	0.97	1.15	1.40±0.05	1.30	1.47
		Force decay	3.80±0.03	3.72	3.83	3.40±0.05	3.33	3.50	2.60±0.09	2.50	2.75

SD: Standard deviation; OT: Ortho technology; AO: American orthodontics

Table 2: Descriptive statistics for elastic chain type divided by elongation in terms of forces (N) before and after incubation as well as the force decay (number of each row=30)

Type	Elongation (%)	Force	Mean±SD	Minimum	Maximum	Percentiles		
						25th	Median	75th
Closed	40	Original	3.30±0.13	3.11	3.56	3.16	3.30	3.41
		Postincubation	1.35±0.32	0.85	1.72	0.95	1.52	1.60
		Force decay	1.95±0.42	1.58	2.60	1.64	1.70	2.50
	60	Original	4.28±0.15	4.00	4.52	4.14	4.30	4.41
		Postincubation	1.54±0.33	0.93	1.90	1.16	1.70	1.79
		Force decay	2.74±0.46	2.30	3.44	2.34	2.56	3.32
	100	Original	5.50±0.12	5.20	5.70	5.40	5.50	5.60
		Postincubation	1.76±0.38	1.10	2.20	1.30	1.99	2.01
		Force decay	3.74±0.42	3.22	4.47	3.39	3.60	4.24
Short	40	Original	2.93±0.13	2.70	3.10	2.80	3.00	3.01
		Postincubation	0.88±0.18	0.60	1.23	0.72	0.83	1.08
		Force decay	2.04±0.10	1.87	2.20	1.94	2.05	2.10
	60	Original	3.80±0.29	3.30	4.15	3.50	3.91	4.03
		Postincubation	1.16±0.22	0.82	1.50	0.98	1.10	1.39
		Force decay	2.64±0.27	2.22	3.10	2.39	2.62	2.96
	100	Original	5.00±0.59	4.18	5.80	4.32	5.00	5.70
		Postincubation	1.41±0.30	1.00	1.82	1.08	1.40	1.78
		Force decay	3.59±0.50	2.81	4.05	2.92	3.90	3.96
Long	40	Original	2.74±0.47	2.00	3.35	2.19	2.90	3.05
		Postincubation	0.99±0.23	0.60	1.30	0.80	1.01	1.20
		Force decay	1.75±0.46	1.00	2.20	1.18	2.01	2.15
	60	Original	3.58±0.54	2.70	4.25	2.99	3.63	4.16
		Postincubation	1.19±0.40	0.60	2.00	0.76	1.18	1.43
		Force decay	2.39±0.67	0.95	3.06	1.72	2.77	2.88
	100	Original	4.60±0.57	3.80	5.40	4.08	4.50	5.30
		Postincubation	1.33±0.20	0.97	1.58	1.14	1.40	1.50
		Force decay	3.27±0.51	2.50	3.83	2.64	3.40	3.80

SD: Standard deviation

were significant (all $P = 0.000000$). The Tukey's *post hoc* test showed that all pairwise comparisons between force decays of different groups were significant [Figure 2 and Table 6]: AO and G&H had the highest and lowest mean force decays, respectively; closed and long chains had the highest and lowest force decays, respectively, though the mean force decay of closed chains was very close to that of short chains; 100% and 40% stretching amounts showed the highest and lowest declines in force, respectively.

Comparing residual (postincubation) forces using the three-way ANOVA showed significant differences among postincubation forces related to brands ($P = 0.000000$), chain types ($P = 0.000000$), and elongation extents ($P = 0.000000$). Interactions were all significant (all $P = 0.000000$). The Tukey's *post hoc* test showed that almost all pairwise comparisons were significant, except the comparison between short- and long-chain types [Figure 2 and Table 6]: OT and AO had the highest and lowest mean final forces, respectively; closed chains had mean residual forces higher than both short and long chains, while postincubation forces of long and short chains were not different significantly; 100% and 40% stretching extents resulted in respectively the highest and lowest final forces.

DISCUSSION

The findings of this study in terms of original preincubation forces indicated that closed chains usually exerted greater initial forces compared to short chains which themselves had greater forces than long chains. The differences between the closed, short, and long chains were the greatest in G&H specimens but were the slightest (though still significant) in OT specimens. The initial force was increased when the chain was stretched more and thus was under a greater traction [Figure 2]. However, those elastomeric chains which had been stretched

Table 3: Descriptive statistics for elastic chain brand divided by chain type in terms of forces (N) before and after incubation as well as the force decay (number of each row=30)

Brand	Type	Force	Mean±SD	Minimum	Maximum	Percentiles		
						25th	Median	75th
OT	Closed	Original	4.23±0.93	3.11	5.47	3.16	4.14	5.40
		Postincubation	1.79±0.25	1.32	2.20	1.57	1.80	2.00
		Force decay	2.44±0.69	1.58	3.42	1.74	2.33	3.28
	Short	Original	4.27±1.12	3.00	5.80	3.07	4.10	5.70
		Postincubation	1.44±0.28	1.06	1.82	1.11	1.43	1.78
		Force decay	2.83±0.84	1.87	4.01	1.94	2.62	3.90
	Long	Original	4.23±0.89	3.00	5.40	3.31	4.21	5.30
		Postincubation	1.40±0.12	1.20	1.58	1.30	1.42	1.50
		Force decay	2.83±0.77	1.80	3.83	2.04	2.78	3.80
AO	Closed	Original	4.48±0.87	3.35	5.65	3.49	4.50	5.50
		Postincubation	1.09±0.15	0.85	1.30	0.93	1.10	1.22
		Force decay	3.39±0.74	2.46	4.47	2.55	3.36	4.24
	Short	Original	3.92±0.89	2.70	5.15	2.99	3.91	4.99
		Postincubation	0.92±0.13	0.70	1.10	0.83	0.92	1.03
		Force decay	3.00±0.77	2.00	4.05	2.15	3.00	3.92
	Long	Original	3.67±0.67	2.70	4.60	3.00	3.63	4.40
		Postincubation	0.84±0.18	0.60	1.15	0.70	0.80	0.99
		Force decay	2.83±0.52	2.08	3.50	2.20	2.92	3.36
G&H	Closed	Original	4.37±0.95	3.20	5.70	3.35	4.30	5.51
		Postincubation	1.78±0.15	1.60	2.10	1.67	1.72	1.92
		Force decay	2.60±0.81	1.60	3.63	1.70	2.56	3.60
	Short	Original	3.53±0.61	2.70	4.42	2.98	3.42	4.26
		Postincubation	1.09±0.27	0.60	1.42	0.80	1.10	1.38
		Force decay	2.45±0.35	2.04	3.00	2.12	2.31	2.88
	Long	Original	3.02±0.79	2.00	4.20	2.19	2.91	3.91
		Postincubation	1.28±0.30	1.00	2.00	1.01	1.18	1.41
		Force decay	1.74±0.66	0.95	2.75	1.14	1.62	2.53

SD: Standard deviation; OT: Ortho technology; AO: American orthodontics

for a greater extent lost more of their forces within a month, compared with those that had been stretched for a smaller degree. The patterns of force decay were not similar for different chain brands and types. In the OT group, the force decay of the long elastomeric chain was usually greater, followed by the short chain; the closed OT chain had the smallest extent of force decay. On the other hand, in the AO group, the closed AO chain had always the greatest mean extent of decay regardless of the extent of stretching; the short and long AO chains showed rather close decay extents in smaller elongations, while the short AO chain showed greater decay in the 100% stretching group. In the G&H group, the results were closer to AO: short chains showed greater decay compared to long chains, while closed chains showed the greatest decay in two out of three subgroups [Figure 2]. The effects of different patterns of force decay caused residual (postincubation) forces, in which the closed chains showed always the greatest postincubation forces, regardless of the brand of elastomeric chains or the extent of stretching. The remaining (postincubation) forces of short and long elastomeric chains were sometimes close to each other and sometimes one type superior to the other one [Figure 2].

The force needed for the bodily movement of teeth can vary between 1 and 3.5 N (between 100 and 350 g)[26-28] although a minimum of 1.5 N might be preferable due to overcoming the friction in clinical practice,[2,3,29] noting that the force preferred by different clinicians might vary considerably.[2,30] Nevertheless, a recent study has shown that forces even below 1 N can still cause proper dental movements.[14] Our results showed that forces that had been degraded after 1 month of incubation were mostly adequate for the bodily movement of teeth, especially in closed elastic chains. This force was proper in closed chains of all brands, almost regardless of the extent of initial elongation (40%, 60%, or 100%). However, many groups of short and long (open) chains showed

Table 4: Descriptive statistics for chain brand divided by stretching extents in terms of forces (N) before and after incubation as well as the force decay (number of each row=30)

Brand	Elongation (%)	Force	Mean±SD	Minimum	Maximum	Percentiles		
						25th	Median	75th
OT	40	Original	3.13±0.11	3.00	3.35	3.02	3.14	3.20
		Postincubation	1.29±0.17	1.06	1.60	1.11	1.26	1.41
		Force decay	1.85±0.15	1.58	2.11	1.74	1.89	1.96
	60	Original	4.13±0.08	4.00	4.25	4.10	4.13	4.20
		Postincubation	1.56±0.19	1.36	1.90	1.40	1.47	1.79
		Force decay	2.57±0.18	2.30	2.80	2.34	2.61	2.74
	100	Original	5.47±0.18	5.20	5.80	5.34	5.41	5.70
		Postincubation	1.79±0.23	1.48	2.20	1.55	1.80	2.00
		Force decay	3.68±0.27	3.22	4.01	3.39	3.80	3.90
AO	40	Original	3.07±0.29	2.70	3.56	2.80	3.00	3.40
		Postincubation	0.81±0.11	0.60	1.00	0.71	0.83	0.90
		Force decay	2.26±0.20	2.00	2.60	2.10	2.20	2.50
	60	Original	4.00±0.37	3.40	4.52	3.69	3.91	4.40
		Postincubation	0.92±0.17	0.60	1.20	0.76	0.92	1.06
		Force decay	3.08±0.22	2.68	3.44	2.92	3.04	3.32
	100	Original	5.00±0.45	4.30	5.65	4.54	5.00	5.50
		Postincubation	1.12±0.11	0.97	1.30	1.03	1.10	1.18
		Force decay	3.88±0.38	3.33	4.47	3.42	3.95	4.24
G&H	40	Original	2.77±0.50	2.00	3.45	2.19	2.83	3.26
		Postincubation	1.14±0.38	0.60	1.72	0.80	1.01	1.60
		Force decay	1.63±0.41	1.00	2.20	1.18	1.66	2.07
	60	Original	3.54±0.57	2.70	4.42	2.99	3.42	4.20
		Postincubation	1.42±0.34	1.08	2.00	1.12	1.18	1.71
		Force decay	2.12±0.50	0.95	2.65	1.72	2.31	2.50
	100	Original	4.62±0.70	3.80	5.70	4.08	4.30	5.51
		Postincubation	1.59±0.28	1.30	2.10	1.38	1.42	1.92
		Force decay	3.03±0.43	2.50	3.63	2.64	2.90	3.60

SD: Standard deviation; OT: Ortho technology; AO: American orthodontics

1-month degraded forces to be below 1 N. Although this is not optimum, it might still suffice to move the teeth into the space.[14] When it comes to the initial forces, we observed clinically proper forces for all types of chains (closed, short, and long) of all brands in the elongations 40% and 60%. However, at the elongation 100%, the initial force can become too strong and probably pathologic regardless of brands and chain types.

Since the force decay in this study was strongly correlated with the initial elongation, the very high initial forces produced at the 100% elongation dampened most rapidly, and the final force created by 100% elongation after 4 weeks became almost similar to forces created by stretching the chains for shorter extents. This contradicts what Andreasen and Bishara[23] had suggested (to stretch the chain to about 400% in order to compensate for the further loss): the more we stretch the elastic chain, the faster it might lose its force; hence, stretching might not be compensating for further loss, not to mention the damage a great initial elongation may inflict. Therefore, it can be suggested, based on experimental evidence for the first time, that the initial elongation should not be set at 100% but at shorter lengths between 40% and 60% because these latter elongations can provide a milder initial force, while at the same time, they may provide 1-month forces very close to 1-month forces induced by higher stretching rates. In this term, we are more inclined to the recommendation of Rock *et al.*[24] who recommended forces not stronger than 50 g. Still, our results showed that what Rock *et al.*[24] suggested might not work for all brands; for certain brands (e.g., OT and G&H), a 40% elongation would suffice to provide proper forces after 1 month, but some other brands (e.g., AO) might lose a greater force in the mouth and thus might need to be elongated greater (closer to 60%), so that they can exert enough forces in longer term. Except the present study, no other study had

Table 5: Descriptive statistics for brands, chain types, elongation extents, and all parameters combined in terms of forces before and after incubation as well as the force decay (N)

Grouping	Force	*n*	Mean±SD	Minimum	Maximum	25th	Median	75th
All sample	Original	270	3.97±0.97	2.00	5.80	3.16	4.00	4.50
	Postincubation	270	1.29±0.39	0.60	2.20	1.00	1.25	1.57
	Force decay	270	2.68±0.81	0.95	4.47	2.08	2.60	3.35
Type								
Closed	Original	90	4.36±0.91	3.11	5.70	3.40	4.30	5.41
	Postincubation	90	1.55±0.38	0.85	2.20	1.20	1.62	1.81
	Force decay	90	2.81±0.85	1.58	4.47	2.32	2.58	3.41
Short	Original	90	3.91±0.94	2.70	5.80	3.00	3.91	4.34
	Postincubation	90	1.15±0.32	0.60	1.82	0.88	1.09	1.40
	Force decay	90	2.76±0.72	1.87	4.05	2.10	2.62	3.04
Long	Original	90	3.64±0.92	2.00	5.40	2.94	3.63	4.24
	Postincubation	90	1.17±0.32	0.60	2.00	0.98	1.18	1.42
	Force decay	90	2.47±0.83	0.95	3.83	1.82	2.59	3.04
Elongation								
40	Original	90	2.99±0.37	2.00	3.56	2.82	3.00	3.26
	Postincubation	90	1.08±0.32	0.60	1.72	0.82	1.01	1.30
	Force decay	90	1.91±0.38	1.00	2.60	1.66	2.00	2.15
60	Original	90	3.89±0.47	2.70	4.52	3.60	4.00	4.20
	Postincubation	90	1.30±0.37	0.60	2.00	1.05	1.20	1.69
	Force decay	90	2.59±0.51	0.95	3.44	2.34	2.62	2.93
100	Original	90	5.03±0.60	3.80	5.80	4.40	5.30	5.50
	Postincubation	90	1.50±0.35	0.97	2.20	1.15	1.42	1.81
	Force decay	90	3.53±0.51	2.50	4.47	3.26	3.60	3.92
Brand								
OT	Original	90	4.24±0.97	3.00	5.80	3.20	4.13	5.35
	Postincubation	90	1.54±0.29	1.06	2.20	1.38	1.50	1.79
	Force decay	90	2.70±0.79	1.58	4.01	1.95	2.61	3.40
AO	Original	90	4.02±0.88	2.70	5.65	3.39	3.91	4.56
	Postincubation	90	0.95±0.18	0.60	1.30	0.81	0.96	1.10
	Force decay	90	3.07±0.72	2.00	4.47	2.50	3.04	3.44
G&H	Original	90	3.64±0.96	2.00	5.70	2.92	3.44	4.28
	Postincubation	90	1.38±0.38	0.60	2.10	1.09	1.39	1.70
	Force decay	90	2.26±0.73	0.95	3.63	1.68	2.31	2.67

SD: Standard deviation; OT: Ortho technology; AO: American orthodontics

compared different extents of elongation. No similar studies existed in this regard for us to compare our results.

In the current study, the highest initial forces belong to OT followed by AO and G&H, noting that the initial force of AO was close to that of OT. On the other hand, AO showed the greatest force decay, followed by OT and G&H which had rather close (though statistically significantly different) decays. OT had the best postincubation forces while AO had the worst ones. Various reasons can contribute to differences observed between brands in this and other studies;[8,10,31] for example, chemical compositions and additives as well as shapes and sizes of chains produced by different companies can differ, leading to various patterns of initial force and force decay.[2,8,18-21]

Overall, among three types of elastic chains in the present study, the closed chains showed the best results compared to open ones (short and long). Among OT chains, the greatest initial forces and the lowest rates of decay were observed in the case of OT closed chains. The results pertaining to closed chains were somehow different in other brands but still quite suitable: closed chains showed the highest initial forces, and albeit their decay extent was greater than other chain types, they still maintained the highest force magnitude after 1 month of incubation. Our results indicated that the behavior of different chain forms in terms of force decay may depend on the brand. In this matter, our results differed from those of Halimi *et al.*[10] who asserted that open chains lose force more rapidly compared to closed chains. Yet, in the current study as well, the overall results pertaining

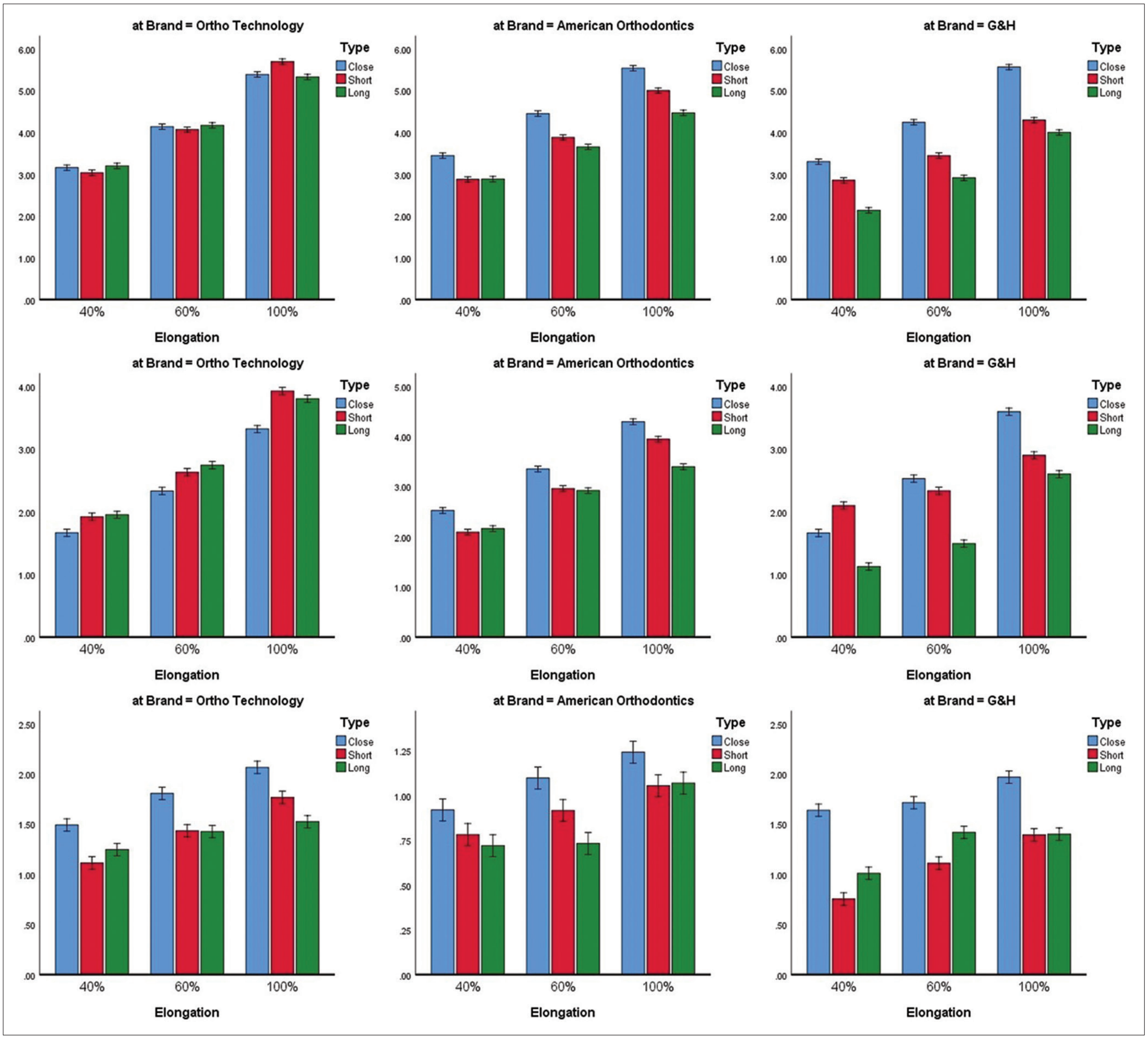

Figure 2: Marginal force means and 95% confidence intervals (Y axis, in Newton) pertaining to preincubation forces (top row), the extents of force decay (middle row), and postincubation forces (bottom row) according to various stretching extents (elongation), different elastomeric chain types, and different chain brands tested.

to closed chains were better than the other two. The other study which had compared closed and open chain types was done by Eliades *et al*.[22] who found no difference between initial forces produced by open and closed chains. They as well did not find any significant difference between the decay rates of both chain types.[22] Nevertheless, in their pilot study, only 10 closed chains had been compared with 10 open chains, both of the same type. Therefore, their sample size might not suffice to obtain proper test powers. No other studies were available on this subject for us to compare our results further.

This study was limited by some factors. An *in vitro* design cannot account for the dynamic environment of the oral cavity. However, this comprehensive multifactorial comparison needed a quite controlled setup that is never possible *in vivo*. Besides, we used artificial saliva and body temperature to simulate partially oral conditions. In addition, a universal testing machine was used instead of digital force gauges in order to ensure high accuracy of results. As another limitation, we did not evaluate the slope of decrease in the force of elastic chains over short time intervals. Nonetheless, most of the literature had

Table 6: The results of Tukey test, comparing different forces (N) among different parameters

Force	Variable	Compared pairs	Difference in force	*P*	95% CI
Original force	Brand	OT			
		AO	0.22	0.0000000	0.18-0.26
		G&H	0.60	0.0000000	0.57-0.64
		AO			
		G&H	0.38	0.0000000	0.35-0.42
	Type	Closed			
		Short	0.45	0.0000000	0.42-0.49
		Long	0.72	0.0000000	0.68-0.76
		Short			
		Long	0.27	0.0000000	0.23-0.30
	Elongation (%)	40			
		60	−0.90	0.0000000	−0.93-−0.86
		100	−2.04	0.0000000	−2.08-−2.00
		60			
		100	−1.14	0.0000000	−1.18-−1.11
Force decay	Brand	OT			
		AO	−0.37	0.0000000	−0.41-−0.34
		G&H	0.44	0.0000000	0.41-0.47
		AO			
		G&H	0.81	0.0000000	0.78-0.85
	Type	Closed			
		Short	0.05	0.001	0.02-0.08
		Long	0.34	0.0000000	0.31-0.37
		Short			
		Long	0.29	0.0000000	0.26-0.32
	Elongation (%)	40			
		60	−0.68	0.0000000	−0.71-−0.64
		100	−1.62	0.0000000	−1.65-−1.59
		60			
		100	−0.94	0.0000000	−0.97-−0.91
Residual force	Brand	OT			
		AO	0.59	0.0000000	0.56-0.63
		G&H	0.16	0.0000000	0.13-0.20
		AO			
		G&H	−0.43	0.0000000	−0.47-−0.40
	Type	Closed			
		Short	0.40	0.0000000	0.37-0.44
		Long	0.38	0.0000000	0.34-0.41
		Short			
		Long	−0.02	0.229	−0.06-0.01
	Elongation (%)	40			
		60	−0.22	0.0000000	−0.25-−0.19
		100	−0.42	0.0000000	−0.46-−0.39
		60			
		100	−0.20	0.0000000	−0.24-−0.17

OT: Ortho technology; AO: American orthodontics; CI: Confidence interval

already assessed that particular aspect (i.e., the pattern of force decreases over time), and therefore, we focused our resources on the assessment of less or not researched aspects within a comprehensive design. This allowed us to reach extremely high test powers. It would be better to evaluate more brands but that would make the number of needed observations much larger; instead, we tried to assess a brand less studied before, i.e., G&H. Our study showed that results pertaining to different chain types or different elongation extents may depend on the brand in use. A recent study has as well shown that there can be notable differences between behaviors of different elastic chain brands with different settings.[31] Thus, it seems that oversimplified generalizations should be avoided, and instead, each future brand should be documented under different stretching or morphological conditions, independently.

CONCLUSION

Overall, OT chains can provide a reasonable (not too high) force decay, resulting in the highest residual forces (compared to other two brands), which were also clinically acceptable. AO chains might show the highest force decay while having the lowest residual forces.

Closed chains showed higher overall initial and residual (and also force decays) compared to short or long chains. In G&H and AO groups, the force decay of closed chains were higher than open chains, yet the residual forces still remained adequate in closed chain groups. In OT chains, results pertaining to closed chains were even better: they showed the highest initial and residual forces while showing the lowest force decays.

Closing the space with an elastic chain stretched for 100% is not recommended because (i) it produces unnecessarily excessive initial forces, and (ii) due to the strong correlation existing between the elongation and force loss, the force decay would be greater when the chain is stretched for 100%, resulting in residual forces not much different from those of chains stretched less. Given the adequacy of both initial and residual forces of chains stretched for 40% and 60%, rates of elongation such as 40% and 60% are recommended, but different brands might need slightly less or more forces.

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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 nonfinancial in this article.

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