

Original Research Article

Residual force analysis of open and closed elastomeric chains for different Pre-stretching percentages-An *in vitro* study

Vaishnavi Vijay^{1*}, Sharath Kumar NS¹, Tanhaz Kareem¹, Kiran Kumar HC¹

¹Dept. of Orthodontics & Dentofacial Orthopaedics, Bapuji Dental College & Hospital, Davanagere, Karnataka, India

Abstract

Objective: To evaluate the residual force of direct-design elastomeric chains (open and closed) different Pre-stretching percentages. **Materials and Methods:** An in-vitro experiment was conducted using open (G-I) and closed (G-II) direct-design elastomeric chains 50%, 75%, and 100% prestretched and tested at measured across eight time intervals F0 (initial), F1 (1h), F2 (1d), F3 (2d), F4 (3d), F5 (7d), F6 (14d), and F7 (21d) using a digital force gauge at 37°C in artificial saliva.

Results: All elastomeric chains exhibited significant force decay in the first 24h, which was followed by a slower, progressive decrease. Closed chains retained significantly higher residual force than open chains across all prestretched levels. Prestretching influenced early forces but had little long-term effect. At 21 days, residual forces (~0.5–0.9 N) were within the optimal orthodontic range.

Conclusion: Closed-chain designs are preferable for sustained force. Elastomeric chains should be replaced approximately every 2 weeks to maintain optimal force delivery.

Keywords: Elastomeric chains, Prestretch, Residual force.

Received: 23-09-2025; **Accepted:** 07-10-2025; **Available Online:** 18-10-2025

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1. Introduction

Elastomeric power chains are among the most frequently used auxiliaries in orthodontics to apply continuous forces for tooth movement, particularly in space closure, midline correction, and anchorage management.^{1,2} The elastomeric chain is a high-molecular-weight polymer made of synthetic rubber, which is made of polyurethane copolymers. The reaction of di-isocyanate and the polymerisation of polyols produce the thermosetting polymer known as polyurethane.³ Introduced in the 1960s, these polyurethane chains gained popularity due to their simplicity, low cost, and patient acceptance.⁴ There are two types of elastomeric chains: open (short/long) and closed (short/long). They can be clear, grey, or have different colours.⁵

The unique properties of elastomeric chains, such as their ability to be easily stretched and their capacity to generate internal stress to return to their initial length, make

them an attractive choice for clinicians for space closure.⁶ Unlike stainless steel coil springs, which deliver relatively constant forces, elastomeric chains are subject to rapid force degradation. This behaviour complicates clinical force control and necessitates frequent reactivation or replacement.^{7,8}

The fundamental biomechanical principle of orthodontic tooth movement dictates that light, continuous forces are more biologically efficient than heavy intermittent forces.^{9,10} Excessive force risks hyalinization of the periodontal ligament (PDL), undermining bone resorption and slowing tooth movement.¹¹ Conversely, forces that decay too quickly may fall below the threshold required for effective movement, leading to treatment inefficiency.¹² Thus, the force delivery profile of elastomeric chains is of central clinical importance.

*Corresponding author: Vaishnavi Vijay
Email: tanhazkareem1997@gmail.com

Numerous studies have documented that elastomeric chains lose between 50% and 70% of their initial force within the first 24 hours, with the steepest loss occurring in the first hour.¹³⁻¹⁵ This early relaxation is attributed to stress relaxation and creep phenomena intrinsic to viscoelastic polyurethane polymers.¹⁶ After this initial drop, force decline continues more gradually over 3–4 weeks, influenced by environmental factors such as moisture, pH fluctuations, and temperature.^{17,18}

Several factors determine the rate and magnitude of force levels. Material composition (thermoplastic vs. thermoset) has been shown to alter mechanical stability, with thermoset polymers typically retaining force better.¹⁹ Pigmentation and additives also affect polymer behavior.²⁰ Design morphology (open vs. closed chain) is another key determinant: closed chains generally sustain force better due to greater cross-sectional bulk.^{21,22} Open chains allow for greater flexibility and may distribute forces more evenly across the dental arch, whereas closed chains provide a more rigid structure that could potentially maintain force more effectively.²³

Finally, prestretching has been proposed to reduce subsequent force loss, though evidence is mixed.^{11,23,24} The technique involves extending the elastic material beyond its resting length prior to clinical placement, allowing the polymer chains to settle and reducing the initial rapid force loss that typically occurs. Research demonstrates that prestretching can significantly reduce stress relaxation compared to control groups.²⁴ The practical benefits of prestretching include, reduction in the need for frequent elastomeric chain replacements, more predictable force delivery over the treatment interval and improved patient comfort by avoiding excessive initial forces.

Although numerous studies have examined elastomeric chain performance, there remains limited evidence directly comparing elastomeric chains in direct design under standardized prestretch conditions. This study was aimed to evaluate the amount of residual forces in various percentage of prestretched open and closed elastomeric chain in direct chain design.

2. Materials and Methods

2.1. Source of the data

The study was performed in the Department of Orthodontics, Oral Pathology, and Microbiology. The institutional review board and ethics committee approved the study (Reg. No. ECR/1652/Inst/KA/2022/23-05/04-006).

2.2. Sample

To minimise inconsistencies arising from counterfeit or compromised materials, the study employed orthodontic elastomeric chains sourced directly from two reputable manufacturers: Sample I- Ormco® Power Chain Generation II Clear in both open (G-I) and closed (G-II) forms, Sample

II- G&H Dyna-Link™ Clear in short and long types. These specific products were selected due to their widespread use in clinical settings and well-recognised standing within the orthodontic field.

2.3. Sample size

The sample size estimation was based on a comparison of force degradation across six distinct groups, using an assumed standard deviation of 55 and mean values of 260 and 230. To achieve a statistical power of 80% at a 5% significance level ($\alpha = 0.05$), a total of 90 samples were needed for each primary group, with 15 samples allocated to each subgroup.

2.5. Sample preparation

For experimental grouping, the samples were divided into two main categories: open chains (Group I) and closed chains (Group II). Each of these groups was further subdivided based on the degree of prestretching applied to the elastomeric chain. Subgroup A consisted of chains prestretched to 50% of their original length, subgroup B consisted of those prestretched to 75%, and subgroup C consisted of those prestretched to 100%. This division was intended to simulate the varying degrees of chain activation commonly encountered in clinical orthodontic practice.

The elastomeric chains with intact internodular links and without any prior stretching were selected for the study. Chains exhibiting any visible structural defects were excluded from the study, as such imperfections could significantly influence the force delivery characteristics. Custom-made acrylic boards, embedded with two rows of 15 stainless steel pins each, served as jigs for mounting the elastomeric chains, which were fixed at a standardised distance of 25 mm apart.

2.6. Force measurement

A calibrated digital force gauge (SF-50, precision $\pm 0.5\%$) was used to record tensile force at eight time points: immediately after activation (F0), 1 hour (F1), 1 day (F2), 2 days (F3), 3 days (F4), 7 days (F5), 14 days (F6), and 21 days (F7). All readings were taken by a single operator to minimise variability.

2.7. Method of study

Two new spools of elastomeric chain from each brand and configuration were used to minimise bias due to prior storage conditions. Each sample consisted of five modules of an elastomeric chain, reflecting the clinical scenario of their use during space closure. The samples were prestretched to 50%, 75%, and 100% of their initial length in accordance with the design of canine retraction mechanics. The initial extension force of each sample was recorded prior to immersion in artificial saliva using the digital force gauge. Following this, the chains were mounted on acrylic jigs and stored in incubators at 37°C throughout the study duration, thereby

maintaining a constant environment that closely approximated intraoral conditions.

Measurements were obtained at sequential intervals to evaluate both initial extension force (F0) and residual force (F1 to F7). (Figure 1) For initial force determination, elastomeric chains were arranged on the acrylic jigs to replicate the mechanics of canine retraction, where the chain extended from the first molar hook, bypassed the second premolar bracket, and engaged onto the canine hook. Samples were stretched across stainless steel pins aligned 25 mm apart to ensure uniformity. Residual force measurements were recorded at predetermined intervals without relaxing the elastomeric chains.

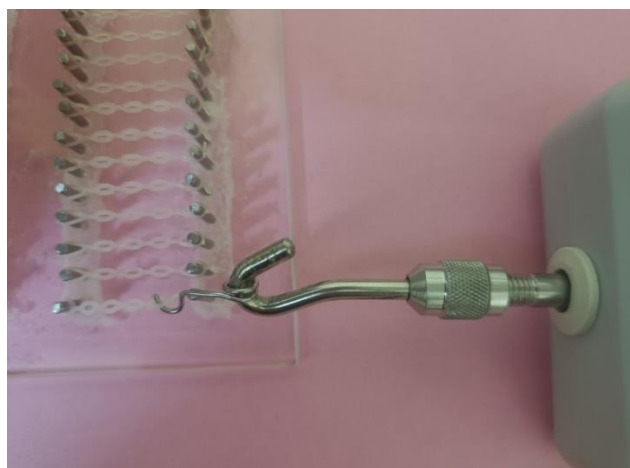


Figure 1: Residual force measurement with force gauge

2.8. Statistical analysis

The data was entered in Microsoft Excel and analysed using SPSS version 23. The data were subjected to the Shapiro-Wilk test to test the normality. The homogeneity of variance

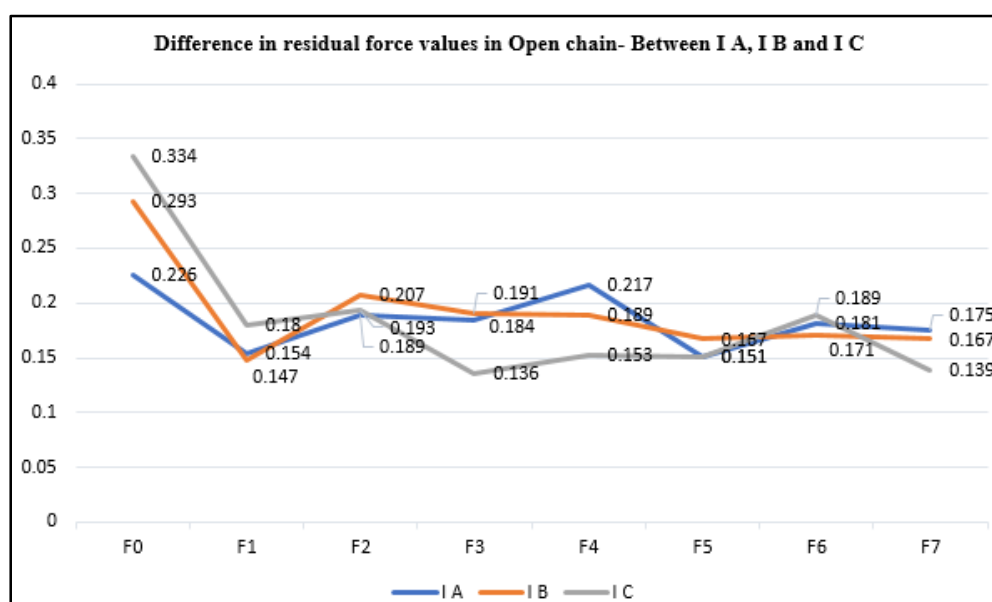
assumption was tested by using the Levene statistic homogeneity of variance. All the variables were following a normal distribution. Hence, a parametric evaluation was adopted. The data was analysed for descriptive and inferential statistics. Descriptive statistics are expressed as mean and standard deviation. The difference in residual force values between open and closed groups of Sample I- Ormco® Power Chain generation II and Sample II- G&H Dyna-Link™ was analysed using unpaired t-test. The difference in residual force values between different time intervals and between sub groups in each group was analysed using one-way- ANOVA followed by Tukey's post hoc analysis. The p-value of 0.05 was considered the level of significance.

3. Results

Across all experimental groups, a consistent pattern was observed: an immediate and significant reduction in force within the first hour, followed by partial recovery or fluctuations during the early days, and subsequent stabilisation toward the later phases of the three weeks. The magnitude of residual force retention was influenced by chain design (open versus closed), degree of pre-stretch, and manufacturer. Closed chains retained more force compared with open chains. Similarly, higher pre-stretching produced greater initial force but was associated with steeper decay over time, especially in open chains.

3.1. Sample I; Group I (Open Chain)

In the 50% pre-stretch subgroup (IA), baseline force values were modest, followed by a sharp decline at one hour. A partial recovery was observed by day 1, after which the values stabilised with minor fluctuations throughout the remaining observation period (**Table 1 and Graph 1**).



Graph 1: Difference in residual force in Sample I; Group I at 50% (I-A), 75% (I-B), 100% (I-C) pre-stretching percentage.

Table 1: Difference in residual force in Sample I; Group I at 50% (I-A), 75% (I-B), 100% (I-C) pre-stretching percentage.

Time periods		n	Mean	SD	SE	Sum of Squares	Mean Square	F	p-value
F0	IA	15	0.226	0.031	0.008	0.089	0.045	97.368	0.000*
	IB	15	0.293	0.018	0.005				
	IC	15	0.334	0.010	0.003				
F1	IA	15	0.154	0.018	0.005	0.009	0.004	12.305	0.000*
	IB	15	0.147	0.023	0.006				
	IC	15	0.180	0.016	0.004				
F2	IA	15	0.189	0.030	0.008	0.003	0.001	2.909	0.066
	IB	15	0.207	0.016	0.004				
	IC	15	0.193	0.012	0.003				
F3	IA	15	0.184	0.033	0.009	0.027	0.013	23.731	0.000*
	IB	15	0.191	0.021	0.005				
	IC	15	0.136	0.013	0.003				
F4	IA	15	0.217	0.044	0.011	0.031	0.015	21.149	0.000*
	IB	15	0.189	0.010	0.002				
	IC	15	0.153	0.013	0.003				
F5	IA	15	0.151	0.019	0.005	0.003	0.001	7.219	0.002*
	IB	15	0.167	0.011	0.003				
	IC	15	0.151	0.010	0.002				
F6	IA	15	0.181	0.037	0.010	0.002	0.001	1.840	0.171
	IB	15	0.171	0.013	0.003				
	IC	15	0.189	0.018	0.005				
F7	IA	15	0.175	0.029	0.008	0.010	0.005	10.813	0.000*
	IB	15	0.167	0.019	0.005				
	IC	15	0.139	0.014	0.004				

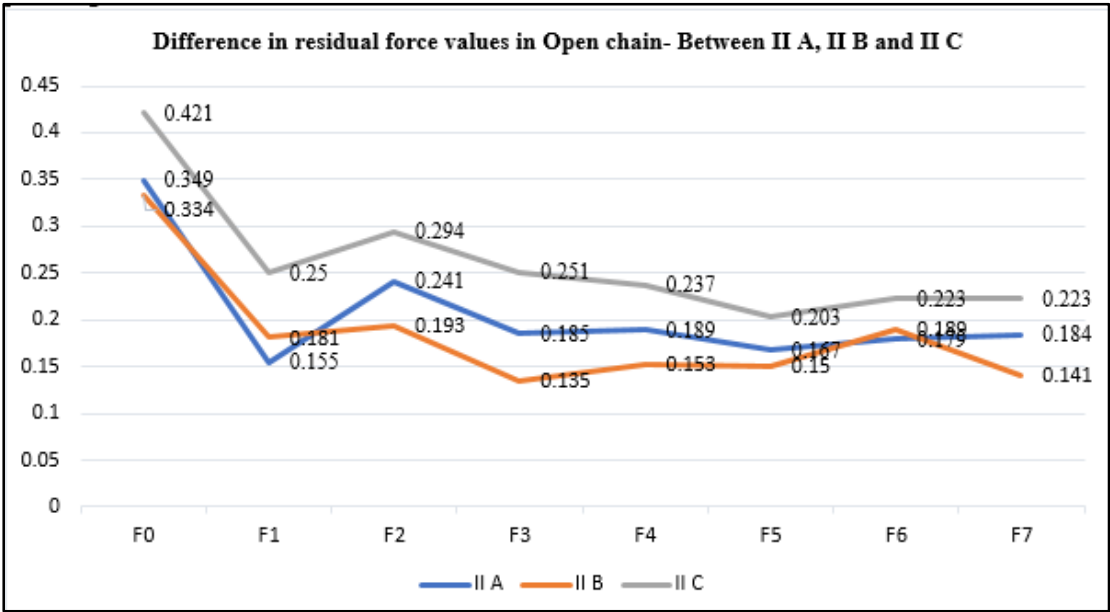
The 75% pre-stretch subgroup (IB) exhibited higher initial forces compared with IA. However, this was followed by a pronounced reduction within one hour. Recovery occurred by day 1, after which forces plateaued at intermediate levels.

The 100% pre-stretch subgroup (IC) demonstrated the highest baseline values among Sample I e-chain. A steep decay was observed within the first hour, with persistent

reductions across subsequent intervals. Despite high initial values, residual forces diminished markedly, highlighting the vulnerability of open chains to rapid relaxation under high pre-stretching conditions.

3.2. Sample I; Group II (Closed chain)

Closed chain configurations consistently outperformed their open chain counterparts, **Table 2 and Graph 2.**



Graph 2: Difference in residual force in Sample I; Group II at 50% (II-A), 75% (II-B), 100% (II-C) pre-stretching percentage

Table 2: Difference in residual force in Sample I; Group II at 50% (II-A), 75% (II-B), 100% (II-C) pre-stretching percentage.

		N	Mean	SD	SE	Sum of Squares	Mean Square	F	p value
F0	IIA	15	0.349	0.007	0.002	0.065	0.033	377.717	0.000*
	IIB	15	0.334	0.009	0.002				
	IIC	15	0.421	0.011	0.003				
F1	IIA	15	0.155	0.008	0.002	0.072	0.036	391.324	0.000*
	IIB	15	0.181	0.012	0.003				
	IIC	15	0.250	0.008	0.002				
F2	IIA	15	0.241	0.018	0.005	0.076	0.038	213.912	0.000*
	IIB	15	0.193	0.013	0.003				
	IIC	15	0.294	0.007	0.002				
F3	IIA	15	0.185	0.021	0.005	0.103	0.051	190.468	0.000*
	IIB	15	0.135	0.014	0.004				
	IIC	15	0.251	0.014	0.004				
F4	IIA	15	0.189	0.016	0.004	0.054	0.027	139.394	0.000*
	IIB	15	0.153	0.010	0.003				
	IIC	15	0.237	0.015	0.004				
F5	IIA	15	0.167	0.015	0.004	0.022	0.011	70.350	0.000*
	IIB	15	0.150	0.008	0.002				
	IIC	15	0.203	0.013	0.003				
F6	IIA	15	0.179	0.009	0.002	0.016	0.008	65.563	0.000*
	IIB	15	0.189	0.011	0.003				
	IIC	15	0.223	0.013	0.003				
F7	IIA	15	0.184	0.012	0.003	0.051	0.026	80.465	0.000*
	IIB	15	0.141	0.013	0.003				
	IIC	15	0.223	0.025	0.007				

The 50% pre-stretch subgroup (IIA) exhibited higher baseline values than IA, with rapid early decline but relative stabilisation beyond the third day.

The 75% pre-stretch subgroup (IIB) displayed significantly elevated baseline forces, which dropped sharply within the first hour but retained greater residual values compared with IB at all subsequent time intervals.

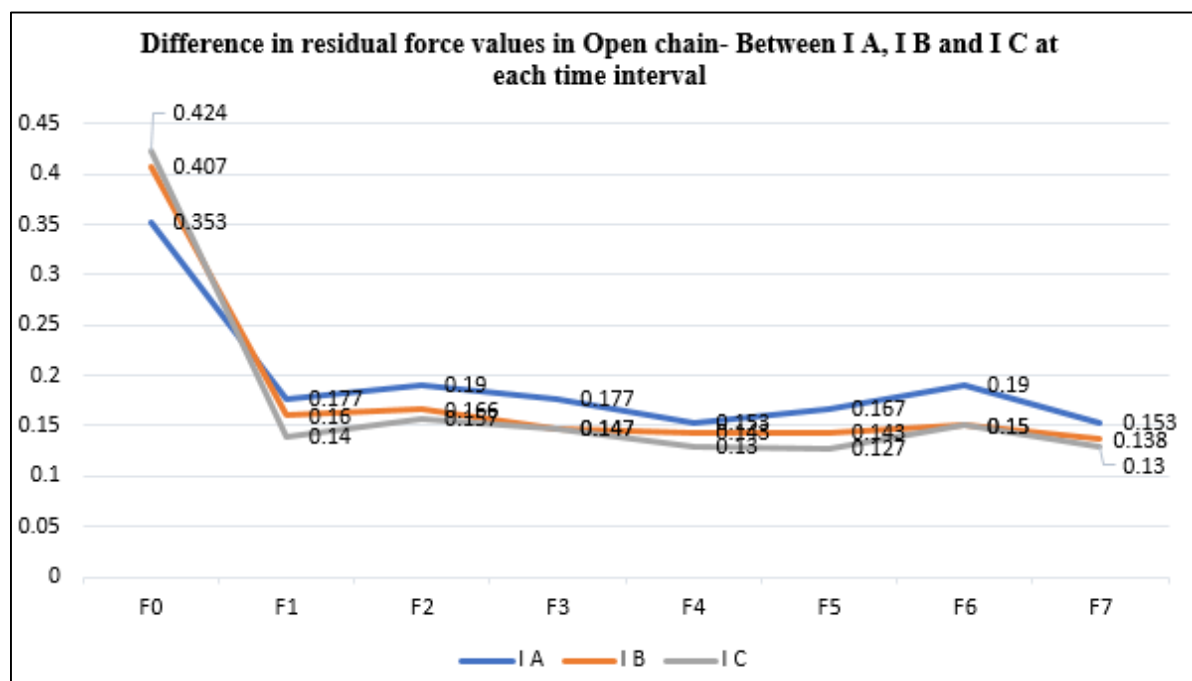
**Graph 3:** Difference in residual force in Sample II; Group I at 50% (I-A), 75% (I-B), 100% (I-C) pre-stretching percentage.

Table 3: Difference in residual force in Sample II; Group I at 50% (I-A), 75% (I-B), 100% (I-C) pre-stretching percentage.

		N		Mean	SD	SE	Sum of Squares	Mean Square	F	p value
F0	IA	15		0.353	0.007	0.002	0.041	0.020	157.474	0.000*
	IB	15		0.407	0.009	0.002				
	IC	15		0.424	0.016	0.004				
F1	IA	15		0.177	0.015	0.004	0.010	0.005	29.345	0.000*
	IB	15		0.160	0.012	0.003				
	IC	15		0.140	0.013	0.003				
F2	IA	15		0.190	0.008	0.002	0.009	0.004	25.543	0.000*
	IB	15		0.166	0.012	0.003				
	IC	15		0.157	0.018	0.005				
F3	IA	15		0.177	0.022	0.006	0.009	0.005	21.977	0.000*
	IB	15		0.147	0.005	0.001				
	IC	15		0.147	0.011	0.003				
F4	IA	15		0.153	0.017	0.004	0.004	0.002	10.702	0.000*
	IB	15		0.143	0.012	0.003				
	IC	15		0.130	0.011	0.003				
F5	IA	15		0.167	0.012	0.003	0.012	0.006	63.583	0.000*
	IB	15		0.143	0.010	0.003				
	IC	15		0.127	0.005	0.001				
F6	IA	15		0.190	0.015	0.004	0.016	0.008	67.200	0.171
	IB	15		0.150	0.008	0.002				
	IC	15		0.150	0.008	0.002				
F7	IA	15		0.153	0.012	0.003	0.004	0.002	16.484	0.000*
	IB	15		0.138	0.010	0.003				
	IC	15		0.130	0.012	0.003				

The 100% pre-stretch subgroup (IIC) showed the highest overall baseline forces (over 0.4 N). Although an immediate drop was observed at one-hour, residual forces remained higher than other Ormco groups throughout the evaluation, confirming superior retention in closed chain designs under maximal pre-stretch.

3.3. Sample II; Group I (Open Chain)

In the 50% pre-stretch subgroup (IA), initial force was higher than the corresponding Ormco group. A steep reduction occurred at one hour, followed by partial recovery at day 1. Subsequent force levels remained relatively stable, although lower than baseline, **Table 3 and Graph 3**.

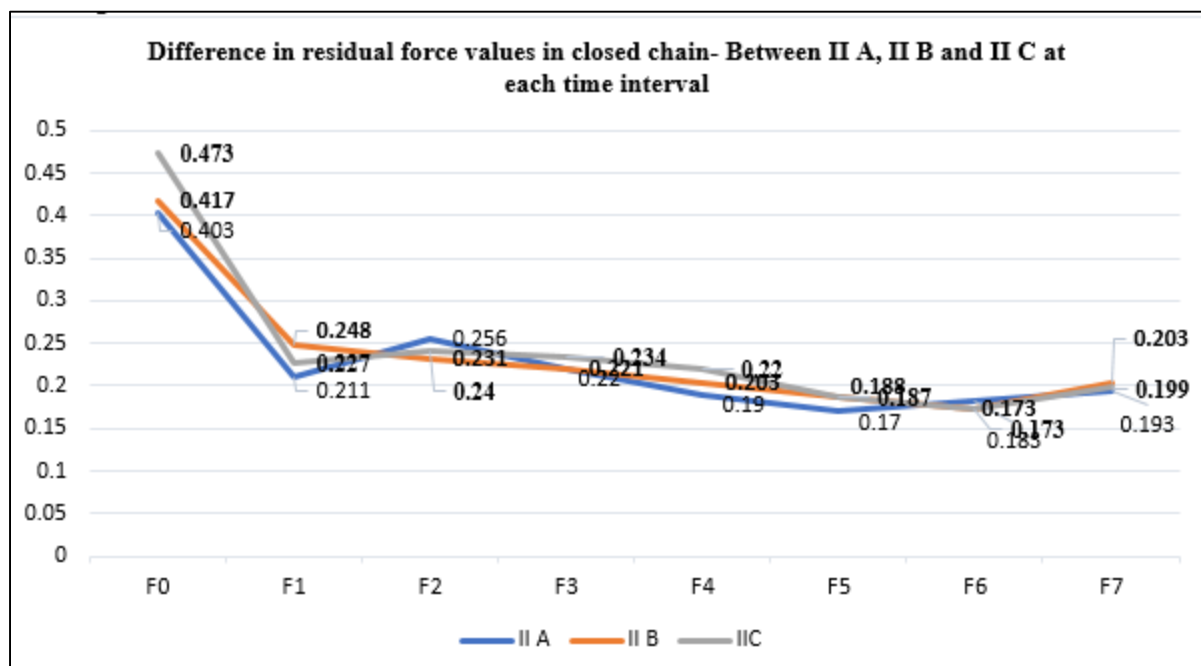
**Graph 4:** Difference in residual force in Sample II; Group II at 50% (II-A), 75% (II-B), 100% (II-C) pre-stretching percentage.

Table 4: Difference in residual force in Sample II; Group II at 50% (II-A), 75% (II-B), 100% (II-C) pre-stretching percentage.

		N	Mean	SD	SE	Sum of Squares	Mean Square	F	p value
F0	IIA	15	0.403	0.014	0.004	0.041	0.021	127.990	0.000*
	IIB	15	0.417	0.012	0.003				
	IIC	15	0.473	0.012	0.003				
F1	IIA	15	0.211	0.022	0.006	0.010	0.005	9.230	0.000*
	IIB	15	0.248	0.029	0.008				
	IIC	15	0.227	0.017	0.004				
F2	IIA	15	0.256	0.009	0.002	0.005	0.002	18.963	0.000*
	IIB	15	0.231	0.015	0.004				
	IIC	15	0.240	0.008	0.002				
F3	IIA	15	0.220	0.016	0.004	0.002	0.001	3.440	0.051
	IIB	15	0.221	0.014	0.004				
	IIC	15	0.234	0.018	0.005				
F4	IIA	15	0.190	0.008	0.002	0.007	0.003	73.621	0.000*
	IIB	15	0.203	0.005	0.001				
	IIC	15	0.220	0.007	0.002				
F5	IIA	15	0.170	0.008	0.002	0.003	0.002	9.944	0.000*
	IIB	15	0.188	0.011	0.003				
	IIC	15	0.187	0.016	0.004				
F6	IIA	15	0.183	0.005	0.001	0.001	0.000	5.833	0.006*
	IIB	15	0.173	0.009	0.002				
	IIC	15	0.173	0.012	0.003				
F7	IIA	15	0.193	0.014	0.004	0.001	0.000	2.871	0.068
	IIB	15	0.203	0.009	0.002				
	IIC	15	0.199	0.011	0.003				

The 75% pre-stretch subgroup (IB) demonstrated high initial forces but steep early decay. Stabilization was reached by day 3, with residual forces lower than baseline but comparable toOrmco closed chains at later intervals.

The 100% pre-stretch subgroup (IC) showed the greatest initial values in the G&H open chain series. However, forces decayed rapidly, with minimal retention by day 7. This underlines the tendency of open chains to lose force rapidly under maximum extension.

3.4. Sample II; Group II (Closed Chain)

Closed-chain subgroups demonstrated superior performance in force retention. The 50% pre-stretch subgroup (IIA) showed higher baseline values than the open chain counterpart, with early decline followed by relative stability from day 3 onwards, **Table 4 and Graph 4**.

The 75% pre-stretch subgroup (IIB) displayed significantly elevated baseline forces, rapid early loss, and subsequent stabilization at comparatively higher levels than Ormco closed chains.

The 100% pre-stretch subgroup (IIC) achieved the highest baseline values of all experimental groups (approaching 0.47 N). Despite an early steep decline, residual forces remained consistently higher than all other groups across every interval, confirming the superior performance of G&H closed chains under maximal pre-stretch.

3.5. Open versus closed chain designs

When directly compared, closed-chain elastomers demonstrated consistently higher residual force retention than open-chain designs across both manufacturers. This difference was particularly significant in the 100% pre-stretch groups, where G&H closed chains (IIC) retained the greatest force levels throughout the 21 days.

Open chains, regardless of manufacturer, were prone to rapid force dissipation, especially under 100% pre-stretch conditions. However, at moderate pre-stretch levels (50% and 75%), some stabilization was observed, albeit at lower residual force magnitudes.

3.6. Influence of pre-stretching

Increasing pre-stretch proportionately elevated the initial force values across all groups. However, higher levels of pre-stretch (especially 100%) were consistently associated with greater early force decay. This trend was more evident in open chains than in closed chains.

Closed chains subjected to 100% pre-stretch maintained significantly higher residual forces throughout the 21-day period compared with open chains at similar levels. These findings highlight that although higher pre-stretch increases initial force delivery, it does not necessarily guarantee improved long-term force retention, particularly for open chains.

4. Discussion

The present in vitro study investigated the residual force patterns of open and closed elastomeric chains subjected to 50%, 75%, and 100% prestretching over a period of 21 days. The findings demonstrated that all chain types exhibited a marked initial force decay within the first hour, followed by fluctuations and a gradual stabilization in the subsequent intervals. This behaviour was consistent across both manufactures, although notable differences in the magnitude of force retention were observed between companies, chain designs, and prestretching protocols.

This aligns with prior observations that closed chains deliver greater initial and residual loads. Mousavi et al.²⁵ found that closed chains exhibited significantly higher initial and residual forces than open chains. Likewise, Halimi et al.⁷ reported that closed chains decayed less quickly than open chains when tested in artificial saliva. The underlying reason is likely geometric; closed chains have more inter-modular material engaged when stretched and thus can bear more load. In this study, closed elastomeric chains remained significantly stronger than their open-chain counterparts at each time point, aligning with these studies.

Kassir et al.⁵ found that closed chains retained 12–20% more force than open ones. G&H exhibited relatively moderate initial force and moderate decay. Kassir et al.³ also noted G&H chains decayed 20–35% by day 21, which is quite close to our results, reinforcing the moderate performance classification.

The percentage of prestretch had a pronounced effect on both initial force and subsequent decay. As expected from viscoelastic material behaviour, chains elongated more (to 75% or 100% beyond their slack length) generated higher starting forces but also suffered proportionally greater force loss. This study shows a strong positive correlation between elongation percentage and total force loss ($r \approx 0.89$). In open chain (Ormco®) group, force decay was notably lower in chains prestretched to 50% compared to 75% and 100%, particularly in Group I A. The 100% prestretched closed chains (Group IIC) retained force better over 21 days than their open counterparts (IC), but still showed substantial decay. This reflects that while increasing the prestretch can increase the initial force, it does not necessarily ensure long-term force stability, potentially due to greater stress relaxation and material fatigue over time, which is supported by previous studies showing rapid initial decay within the first 24 hours followed by a plateau phase.¹⁵

These findings hold important clinical implications for canine retraction, where a continuous and controlled force of approximately 150–200 g is ideal for optimal tooth movement while minimizing adverse effects like root resorption and patient discomfort.²⁶ The present study indicates that without timely replacement or reactivation, elastomeric chains, especially open ones or those

prestretched to high levels, may fall below the optimal force threshold within the first week of use, compromising the efficiency of retraction.

Notably, open chains (G&H™) prestretched to 100% (Group IC) retained higher force levels than corresponding closed chains (Group IIC), especially at time points F1–F5. This is in contrast with other literature that typically favours closed chains for force retention,¹⁴ suggesting possible differences in proprietary manufacturing processes, polymer composition, or molecular cross-linking densities among brands.

Statistical analyses using one way ANOVA and Tukey's post hoc tests confirmed that the differences in force decay were significant between most groups across all time intervals ($p < 0.05$), reinforcing the need for product-specific guidelines on replacement intervals and prestretching protocols.

4.1. Clinical implications

The clinical relevance of these findings lies in selecting the appropriate chain design, prestretching protocol, and reactivation schedule. While prestretching produces higher initial forces, it may not guarantee prolonged force delivery. Closed chains appear more reliable in maintaining force within the optimal range over 3 weeks, making them advantageous for space closure. Open chains, on the other hand, exhibit greater fluctuations and earlier relaxation, suggesting a need for more frequent reactivations. Furthermore, brand-specific variations observed in this study highlight that clinicians cannot assume uniform performance across manufacturers, a point supported by prior comparative studies. Regular monitoring and timely replacement of chains remain essential for predictable tooth movement.

4.2. Limitations

This study was conducted under in vitro conditions, which cannot entirely replicate the complex oral environment where factors such as saliva, temperature fluctuations, pH changes, and masticatory forces may further accelerate degradation. Future investigations should incorporate in vivo methodologies, evaluate the influence of pigmentation and additives, and explore novel polymer modifications aimed at reducing force degradation.

5. Conclusion

1. Elastomeric chains undergo substantial early force decay, followed by a stabilization phase, with closed chains retaining forces more effectively than open designs.
2. Prestretching, while enhancing initial force, does not ensure superior long-term performance and may hasten relaxation depending on material properties. Importantly, despite early force loss, residual forces often fall within the biologically optimal range,

supporting their continued use in fixed orthodontic mechanics.

3. Clinicians should customise chain type and reactivation schedules to individual treatment needs, guided by the biological principles of optimal force application.

6. Source of Funding

None.

7. Conflict of Interest

None.

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Cite this article: Vijay V, Sharath Kumar NS, Kareem T, Kiran Kumar HC. Residual force analysis of open and closed elastomeric chains for different Pre-stretching percentages-An *in vitro* study. *J Pierre Fauchard Acad.* 2025;39(3):81-89.