



An Evaluation of Force Decay in Elastomeric Chain and Active Tieback: An in Vitro Study

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Abstract

Objective: This in-vitro study aimed to evaluate and compare the force decay of elastomeric chains and active tiebacks from three different orthodontic brands—3M, D-Tech, and Kodan—over a 28-day period, subjected to double and triple elongation levels. Materials and **Methods:** Elastomeric chains and active tiebacks from each brand were stretched to double and triple their original lengths and submerged in artificial saliva and maintained at room temperature throughout the testing period. A total of 252 specimens were tested—126 for

elastomeric chains and 126 for active tiebacks—divided equally among the three brands and elongation groups. Force measurements were recorded using a force gauge (correx) at 1 day (T1), 7 days (T2), 14 days (T3), 21 days (T4), and 28 days (T5). Data were analyzed using one-way ANOVA and Bonferroni post-hoc test in SPSS Version 26.0.

Results: All tested materials exhibited a significant decrease in force over time ($p < 0.05$). At both elongation levels continuous elastomeric chains demonstrated greater force retention compared to Active

tieback across all brands. Among the three, 3M products showed the least force degradation, followed by D-Tech and Kodan.

Conclusion: Continuous elastomeric chains maintained more consistent force levels than Active tieback over 28 days. The findings suggest that brand selection and appropriate elongation are critical for optimizing orthodontic force application. 3M products demonstrated superior performance in terms of force stability, underscoring the importance of material quality in clinical orthodontic practice.

Keywords: Force Decay, Elastomeric Chain, Active Tieback, Orthodontics, In-Vitro Study, Force Retention, 3M, Kodan, D-Tech.

Introduction

Orthodontic tooth movement depends on the application of controlled and continuous forces to achieve functional and aesthetic treatment goals. Among the many force-generating systems used in orthodontics, elastomeric chains and active tiebacks have become essential tools due to their ease of use, versatility, and clinical effectiveness in space closure and retraction mechanics. However, a major limitation of these systems is force decay—a gradual reduction in the applied force due to environmental and mechanical factors—which can compromise treatment efficiency and outcomes^{1,2}.

Elastomeric chains, primarily made from polyurethane, initially provide effective force levels but are highly susceptible to rapid degradation when exposed to oral conditions like temperature fluctuations, humidity, salivary enzymes, and stress relaxation. Studies report a significant force loss—sometimes more than 50%—within the first 24 hours of intraoral application.^{3,4} Stretching, stress relaxation, and repeated mechanical loading further accelerate this degradation, requiring

frequent replacements during treatment.⁵ Although pre-stretching has been proposed to offset early force loss, research suggests that long-term degradation patterns remain unchanged.⁶

In contrast, active tiebacks—commonly fabricated from stainless steel or nickel-titanium—are more stable under intraoral conditions. They resist environmental degradation better than elastomeric chains but are not immune to stress relaxation and mechanical fatigue over time. Their force retention is influenced by alloy composition, surface treatments, and manufacturing processes, which vary across brands and can affect their clinical performance.⁷⁻⁹

The clinical implications of force decay are significant. Insufficient or unpredictable force levels can delay treatment progress, while excessive initial forces may lead to undesirable outcomes such as root resorption or anchorage loss.^{10,11} Despite numerous studies, variations in materials and experimental designs have led to inconsistent findings, especially regarding brand-specific differences in force retention.

Given these concerns, this study seeks to comprehensively evaluate and compare the force decay characteristics of elastomeric chains and active tiebacks under standardized laboratory conditions. By simulating intraoral environments and monitoring force levels over time, the study aims to provide reliable data that can guide material selection and support evidence-based orthodontic practice for improved treatment efficiency and predictability.³

Material & Methodology

This experimental in vitro study was designed to evaluate and compare the force decay characteristics of elastomeric chains and active tiebacks from three widely used orthodontic brands—3M Unitek, D-Tech, and

KODEN—under standardized conditions. The study was conducted at the Department of Orthodontics and Dentofacial Orthopaedics, Malabar Dental College and Research Centre, over a duration of six months. Ethical clearance was obtained from the Institutional Ethical Committee (IEC/05/ORTHO-B/MDC/2022-23) prior to initiation.

A total of 252 samples were analyzed, classified into six groups: three comprising continuous elastomeric chains and three comprising active tiebacks, with 42 samples in each group. Each group was further subdivided based on two levels of elongation: double (2×) and triple (3×) the original length, resulting in 21 samples per subgroup. The initial unstretched length for elastomeric chains was standardized to 15 mm and for modules to 2 mm. Based on this, double and triple elongation corresponded to 30 mm and 45 mm for chains, and 4 mm and 6 mm for modules, respectively.

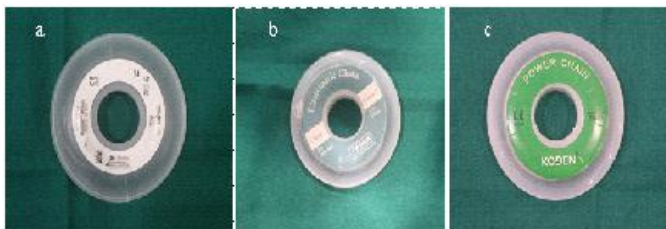


Figure 1: (a) 3M Unitek, (b) D-Tech, and (c) KODEN elastomeric chain

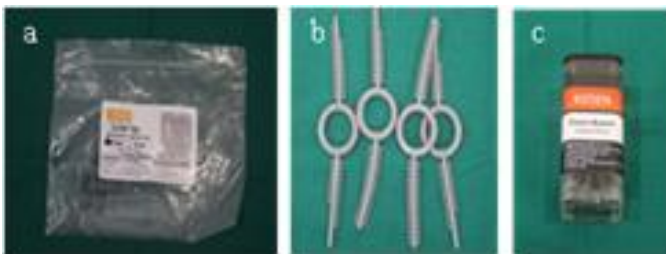


Figure 2: (a) D-Tech, (b) 3M Unitek and (c) KODEN elastic module

Custom-made acrylic plates (50 cm × 16 cm) embedded with stainless steel nails were fabricated to securely stretch and mount the samples at the designated lengths.

Three plates were allocated for chains and three for tiebacks. The mounted samples were completely immersed in artificial saliva composed of NaCl, KCl, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$, $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$, and urea to simulate the intraoral environment. All samples were stored at room temperature (approximately 37°C) throughout the experimental period.



Figure 3: Custom-made acrylic plates immersed in artificial saliva



Figure 4: Force measuring instrument (Correx gauge)

Force measurements were conducted at five-time intervals: Day 1, Day 7, Day 14, Day 21, and Day 28, using a Correx force gauge, which provided readings in grams. Each sample was measured in triplicate to minimize variability, and the mean value was recorded for analysis. Measurements were consistently performed by the same examiner to reduce operator-related bias.

Inclusion criteria consisted of continuous elastomeric chains and ligature wires (0.009-inch diameter) with standardized modules (1.3 mm internal diameter, 3.1 mm external diameter, 0.9 mm thickness). Materials were excluded if they exhibited any visible manufacturing or storage defects or had exceeded their expiration date.

The study aimed to simulate clinical conditions as closely as possible in a controlled environment, ensuring consistency and reproducibility. Statistical analysis included descriptive measures and inferential tests such as repeated-measures ANOVA and Tukey's post hoc test to evaluate differences in force decay across time intervals, stretch levels, and brands. Significance was set at $p < 0.05$. This methodology allows a comprehensive comparison of force degradation patterns in orthodontic elastomers, offering valuable insights for optimizing material selection and improving clinical efficiency in space closure mechanics.

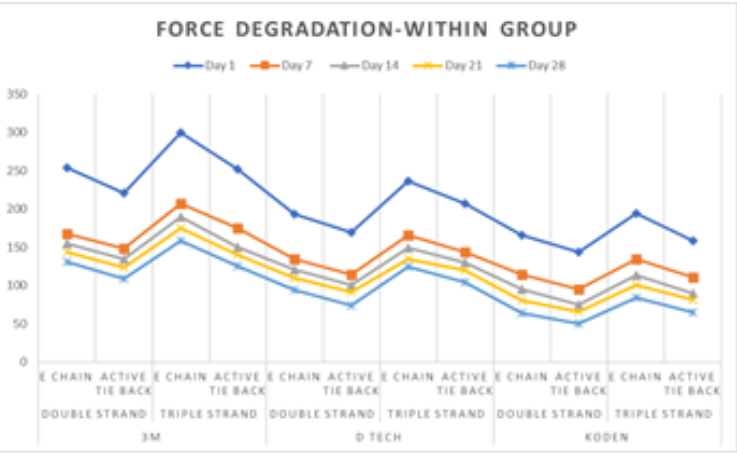
Result

Data was analyzed using the statistical package SPSS 26.0 (SPSS Inc., Chicago, IL) and level of significance was set at $p < 0.05$. Descriptive statistics was performed to assess the mean and standard deviation of the respective groups. Normality of the data was assessed using Shapiro Wilk test. Inferential statistics to find out the difference within the groups was done using Repeated measures of Anova test followed by Bonferroni Posthoc test. Between the groups analysis was done using Independent T Test.

The within-group comparison of force values over 28 days showed a progressive decline in force across all elastomeric chains and active tie-back configurations. On Day 1, all groups exhibited their highest force levels, with triple-strand configurations consistently producing significantly higher forces than their double-strand counterparts, as indicated by the asterisks. Among the three brands—3M, D TECH, and KODEN—the 3M products demonstrated both the highest initial forces and relatively better retention over time. Although all

materials showed force degradation over the four-week period, the decline was most prominent within the first 14 days. The posthoc comparisons confirmed statistically significant changes at various time points, particularly between Day 1 and Day 14, and between Day 14 and Day 28. These results suggest that triple-strand elastomeric chains provide a significantly stronger initial force, but all configurations experience notable degradation over time. Clinically, this underscores the need for regular replacement—typically around the two-week mark—to maintain effective and consistent orthodontic force levels. (Table 1, Graph 1)

Table 2 presents the between-group comparison of force values for elastomeric chains and active tie-backs from three different brands—3M, D TECH, and KODEN—tested in both double and triple strands across five time points (Day 1 to Day 28). Across all time points, 3M products consistently exhibited significantly higher force values than both D TECH and KODEN, as indicated by the asterisks. This trend was evident for both double and triple strand configurations, and for both elastomeric chains and active tie-backs. Triple strands in each brand and category also produced higher forces than their double strand counterparts, though 3M still maintained the overall lead in force magnitude. While all brands showed a gradual decline in force over time, the initial and retained forces of 3M remained significantly higher compared to D TECH and KODEN, suggesting superior force durability. These findings underscore the mechanical advantage of 3M elastomeric products in orthodontic applications where sustained force is critical for tooth movement.



Graph 1: Force Degradation-Within Group

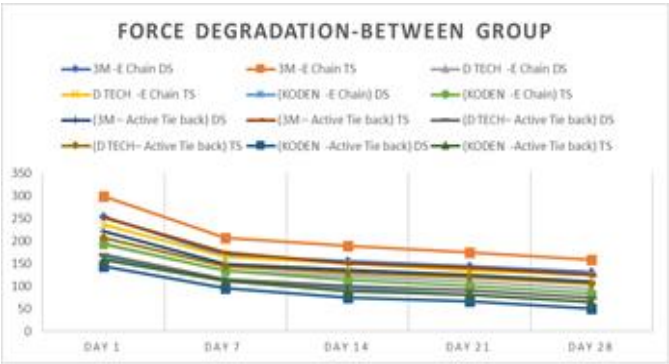
Table 1: Comparison of force within group

	3M -E Chain		D TECH -E Chain		(KODEN -E Chain)		(3M – Active Tie back)		(D TECH– Active Tie back)		(KODEN -Active Tie back)	
	Double Stretched	Triple Stretched	Double Stretched	Triple Stretched	Double Stretched	Triple Stretched	Double Stretched	Triple Stretched	Double Stretched	Triple Stretched	Double Stretched	Triple Stretched
Day 1	254.04 ±2.93	299.28 ±4.*	192.85± 3.9	235.95± 2.4.*	165.48± 2.6	194.04±2 .4.*	220.95± 5.2	251.67± 3.21.*	169.04± 3.65.	206.67± 4.72.*	144.04± 2.49	158.09±3 .26.*
Day 7	167.86 ±4.24	207.14 ±4.5.*	134.76± 2.4	165.47± 2.6.*	114.76± 2.4	134.29±2 .3	148.09± 3.2	174.52 ±2.63.*	114.05± 2.49	144.05± 2.49.*	94.76±2 .42	111.19±2 .12.*
Day 14	154.52 ±2.62	189.52 ±2.6.*	121.19± 2.1	149.52± 2.1.*	94.76±2 .37	113.57±2 .2.*	135±2.6 7	150±2. 67.*	100.24± 2.42	129.53± 2.63.*	74.75±2 .38	89.5±2.5 7.*
Day 21	143.57 ±2.25	174.76 ±2.4.*	109.76± 2.4	134.28± 1.7.*	80.23±2 .43	100.23±2 .4.*	123.81± 2.1	140.24 ±2.43.*	91.19±2 .12	120±2. 67.*	65.47±2 .63	81.42±2. 26.*
Day 28	130.47 ±2.63	158.81 ±2.1.*	94.04±1 .96	124.04± 1.9.*	64.04±2 .49	83.81±2. 12.*	109.29± 2.3	125±2. 68.*	74.28±2 .34	104.28± 2.33.*	50.47±2 .63	65.23±2. 88.*
Posthoc significa nce (	1 vs 14 14 vs 21 21 vs 28	1 vs 14 14 vs 21 21 vs 28	1 vs 14 14 vs 21 21 vs 28	1 vs 14 14 vs 21 21 vs 28	14 vs 21 21 vs 28	14 vs 21 21 vs 28	1 vs 14 7 vs 14 14 vs 21 14 vs 28 21 vs 28	14 vs 21 21 vs 28	1 vs 14 14 vs 21 21 vs 28	1 vs 14 7 vs 21 14 vs 21 21 vs 28	14 vs 21 21 vs 28	14 vs 21 21 vs 28

Table 2: Comparison of force between group

	3M				D TECH				KODEN			
	Double Stretched		Triple Stretched		Double Stretched		Triple Stretched		Double Stretched		Triple Stretched	
	E Chain	Active Tie back	E Chain	Active Tie back	E Chain	Active Tie back	E Chain	Active Tie back	E Chain	Active Tie back	E Chain	Active Tie back
Day 1	254.04± 2.93*	220.95 ±5.25	299.28 ±4.71*	251.67± 3.21	192.85± 3.95*	169.04± 3.65	235.95± 2.49*	206.67± 4.72	165.48± 2.63*	144.04± 2.49	194.04± 2.49*	158.09± 3.26
Day 7	167.86± 4.24*	148.09 ±3.26	207.14 ±4.52*	174.52± 2.63	134.76± 2.42*	114.05± 2.49	165.47± 2.63*	144.05± 2.49	114.76± 2.42*	94.76±2. 42	134.29± 2.34*	111.19± 2.12

Day 14	154.52±2.62*	135±2.67	189.52±2.62*	150±2.67	121.19±2.12*	100.24±2.42	149.52±2.12*	129.53±2.63	94.76±2.37*	74.75±2.38	113.57±2.21*	89.5±2.57
Day 21	143.57±2.25*	123.81±2.13	174.76±2.42*	140.24±2.43	109.76±2.42*	91.19±2.12	134.28±1.74*	120±2.67	80.23±2.43*	65.47±2.63	100.23±2.42*	81.42±2.26
Day 28	130.47±2.63*	109.29±2.34	158.81±2.12*	125±2.68	94.04±1.96*	74.28±2.34	124.04±1.96*	104.28±2.33	64.04±2.49*	50.47±2.63	83.81±2.12*	65.23±2.88



Graph 2: Force Degradation-Between Group

Discussion

Orthodontic tooth movement relies on the application of sustained, light forces, especially during the initial phases of bodily tooth movement. However, overcoming resistance from periodontal ligament fibers often necessitates a rise in force levels over time. Elastomeric chains and active tiebacks are commonly used in such scenarios due to their ease of application and cost-effectiveness, though their clinical efficacy is limited by force degradation.

The current in vitro study evaluated and compared the force decay of elastomeric chains and active tiebacks from three different manufacturers—3M, D-Tech, and KODEN—over a 28-day period under simulated intraoral conditions. Force measurements were recorded at five specific intervals (Day 1, 7, 14, 21, and 28), following double and triple elongation protocols.

Artificial saliva and room temperature were employed to replicate intraoral conditions, as supported by Taloumis et al.¹¹ and Lu et al. (1993)¹², ensuring reliable simulation of the oral environment.

Consistent with previous literature, this study reaffirmed that a significant portion of force loss occurs within the first 24 hours post-activation, followed by a slower, progressive decline over the remaining observation period (1,2,3,4). The amount of force required for space closure during retraction has been widely discussed in orthodontic literature, with the optimal range considered to be between 150 g to 200 g per side to achieve efficient tooth movement without undue risk of anchorage loss or root resorption. In the present study, both elastomeric chains and active tie-backs were evaluated for their ability to generate and maintain these clinically effective force levels over a 28-day period.

On Day 1, all groups—irrespective of brand or configuration—generated forces well above the minimum threshold required for retraction, with triple-strand configurations consistently exceeding 200 g and double-strand configurations producing forces closer to the lower end of the desired range. However, due to the progressive force decay observed, particularly within the first 14 days, not all brands were able to maintain forces within the clinically acceptable range throughout the experimental period.

The initial force values and overall retention varied significantly among the brands. Elastomeric chains from 3M consistently demonstrated superior force retention across all time intervals and both elongation protocols, with values in both double- and triple-strand groups remaining closer to the optimal retraction force even after 14 and 28 days. These findings align with the

observations of Lu et al. (1993)¹² and Ramachandraiah S et al. (2017)¹³, who attributed better performance to improved polymer quality and cross-linking technology used by premium brands. In contrast, KODEN exhibited the highest force decay, particularly in active tiebacks, echoing the findings of Ahrari F et al. (2010)¹⁴, who reported rapid force loss in products with suboptimal polymer composition.

Across all groups, force decay was statistically significant ($p < 0.05$), with the most dramatic reduction occurring between Day 1 and Day 7—a pattern previously reported by Andreasen & Bishara (1970)⁶, Wong AK (1976)², and Josell SD et al. (1997)¹⁵. These studies also observed stabilization of force levels following the first week, a trend reflected in the present findings.

A comparison between elastomeric chains and active tiebacks revealed that chains retained significantly more force over time. This is consistent with results from Santos et al. (2008)¹⁶, Ramachandraiah et al. (2017)¹³, and Russell et al. (2001)¹⁷, who suggested that the ligature modules in tiebacks create structural discontinuities, promoting faster relaxation and creep. However, studies such as Kovatch et al. (2010)¹⁸ have contradicted these findings, reporting no significant differences between the two systems—indicating the influence of design variability and material composition. The composition of elastomeric materials also played a crucial role. Superior performance of 3M products was likely due to advanced polyurethane synthesis and cross-linking technologies that reduce hydrolytic degradation^{11,19}. D-Tech materials showed intermediate force retention, suggesting moderately optimized material properties, while KODEN's inferior

performance suggests a need for improved manufacturing protocols.

Interestingly, the force decay trend relative to elongation revealed that double-stretched specimens exhibited more degradation than triple-stretched ones in most groups. This is contrary to the general belief that higher elongation accelerates relaxation, as proposed by Varner RE & Buck DL (1978)²⁰. However, findings by Santos ACS et al. (2007)¹⁶ and Genova DC et al. (1985)²¹ support our observation, proposing that triple stretching may induce internal polymer chain alignment that promotes more stable force delivery over time.

Temporal patterns revealed through Bonferroni post hoc analysis demonstrated that while the most substantial degradation occurred by Day 7, notable decline continued through Day 14 and stabilized by Day 28. This agrees with the results reported by Wong (1976)² and Rock WP et al. (1986)²², who found the highest rate of force decay early in the activation period, followed by a plateau in degradation rates.

Active tiebacks exhibited a more uniform but steady force loss, likely due to their modular design distributing stress more evenly, but also experiencing earlier micro-creep. Baty et al. (1994)³ supported this observation by attributing faster relaxation in ligature-based tiebacks to stress concentration and material fatigue at points of curvature and contact.

Clinical Implication

From a clinical standpoint, the results highlight the necessity of timely reactivation of elastomeric forces, particularly within the 28 days, to ensure optimal and consistent tooth movement. Furthermore, the superiority of 3M products in terms of force sustainability suggests they may be preferable in cases requiring extended intervals between appointments. However, it is essential

to recognize that in vivo conditions introduce variables like enzymatic degradation, pH fluctuations, mastication forces, and temperature changes that could alter degradation. Thus, while in vitro findings provide valuable insight, in vivo verification remains critical for comprehensive material evaluation.

Limitation

While in vitro designs allow for control over variables, they cannot fully replicate the complexity of the oral environment, including masticatory forces, enzymatic degradation, and thermal cycling. Future studies should explore the impact of such variables using in vivo designs or thermocycling protocols. Additionally, incorporating scanning electron microscopy (SEM) to assess surface degradation could provide valuable insights into material wear. One limitation of this study was the exclusion of cyclic loading and thermal cycling, which more accurately reflect intraoral conditions. Future studies incorporating these factors along with in vivo trials could further validate our observation.

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