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Influence of Different Temperature Ranges on the Level of Force in Elastic Chains: An In Vitro Study

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ABSTRACT:

Background: Orthodontic elastomeric chains are commonly used for space closure and tooth movement; however, their mechanical efficiency is significantly influenced by environmental factors, particularly temperature.

Aim: This in vitro study aimed to evaluate and compare the effects of different temperature ranges on the force degradation of conventional orthodontic elastic chains.

Materials and Methods: Twenty continuous-type orthodontic power chains (14 mm length, 5 lumens each) were divided into four groups ($n = 5$) and immersed in water at different temperatures: 5°C, 25°C, 37°C, and 60°C. Each specimen was stretched to 28 mm (100%) and tested for tensile force using a Dontrix gauge before and after a 140-minute immersion. Force reduction was calculated, and statistical analysis was performed using one-way ANOVA.

Results: Force degradation increased significantly with temperature. The mean percentage of force loss was 8% at 5°C, 12% at 25°C, 18% at 37°C, and 38% at 60°C. The differences between groups were statistically significant ($P < 0.05$).

Conclusion: Temperature exerts a substantial influence on the force retention of elastic chains. Higher temperatures accelerate force degradation, potentially compromising clinical effectiveness. Orthodontists should advise patients regarding temperature-induced changes and suggest dietary habits that help maintain optimal appliance performance.

Introduction

Orthodontic elastic chains, commonly referred to as power chains or e-chains, are an integral part of modern fixed orthodontic treatment. They are routinely employed to facilitate tooth movement by exerting a consistent, continuous force over a period of time. These elastic chains are typically fabricated from medical-grade polyurethane elastomeric material, known for its high elasticity, biocompatibility, and ability to maintain a stable force during clinical use. Power chains are most frequently used for space closure, aligning teeth, and achieving other controlled movements such as midline correction and tooth rotations. The application of elastic chains in orthodontics has grown in popularity due to several inherent advantages. These include ease of placement, minimal reliance on patient compliance, cost-effectiveness, relative hygiene maintenance, and versatility in both function and aesthetic options, as they are available in a wide array of colors. Despite these advantages, a significant limitation is their susceptibility to force degradation over time. The force produced by elastomeric chains is not permanent; it diminishes gradually, and this degradation is largely irreversible. Consequently, power chains must be replaced periodically during treatment to ensure consistent force application and desirable tooth movement[1]. Among various factors contributing to the degradation of force, oral temperature plays a critical role. The oral cavity is a dynamic environment where temperature fluctuates frequently, influenced not only by metabolic and physiological processes but also by dietary habits and environmental exposure. Previous studies have shown that the mechanical properties of elastomeric materials are sensitive to thermal changes; increased temperature accelerates the relaxation of elastic polymers, resulting in faster force decay[2]. For instance, research by Taloumis et al. (1997) demonstrated that elastomeric chains exposed to body temperature (approximately 37°C) exhibited a greater reduction in force compared to those maintained at room temperature (23°C)[5]. Furthermore, global dietary habits introduce significant variability in intraoral temperature. Cultural practices influence not just the types of food consumed but also the temperature at which food and beverages are typically ingested. For example, individuals in South American regions commonly drink cold water with meals, while Europeans prefer room-temperature water. In contrast, populations in many Asian countries frequently consume hot water or tea during meals[3]. These habitual preferences lead to cyclical fluctuations in oral temperature throughout the day, which may directly affect the performance of orthodontic elastomeric chains. Additionally, the intake of food and beverages of varying temperatures has been reported to cause short-term increases or decreases in oral temperature, potentially creating micro-environmental changes that influence the mechanical behaviour of orthodontic materials[4]. Such variations can alter the viscoelastic properties of elastomers, impacting their ability to sustain the desired orthodontic forces over time. This inconsistency in force delivery poses a clinical challenge, particularly when determining the optimal interval for replacing the power chain to ensure effective and predictable tooth movement[6]. Given the importance of maintaining consistent force levels during orthodontic therapy, it is essential to understand how thermal exposure affects elastomeric chain behaviour. While various brands of power chains may exhibit differing responses to thermal changes, it is generally accepted that elevated temperatures accelerate force degradation[5]. This necessitates a better understanding of how commonly encountered oral temperature conditions—whether from natural physiological variations or thermal influences due to food and drink—can affect the clinical performance of elastomeric chains. Therefore, this in vitro study aims to evaluate the influence of different temperature ranges on the initial and residual force levels exerted by orthodontic power chains. By simulating oral temperature variations in a controlled laboratory setting, this research seeks to provide clinically relevant insights into the behaviour of elastomeric chains under conditions that mimic real-life intraoral environments. The results may assist clinicians in making informed decisions about material selection, replacement intervals, and patient instructions, thereby contributing to more effective and efficient orthodontic treatment outcomes.

Materials and Methodology

This laboratory-based in-vitro study was carried out in the Department of Orthodontics and Dentofacial Orthopedics at Bhabha College of Dental Sciences, Bhopal, with the main objective of assessing how different temperature conditions influence the tensile strength of orthodontic elastomeric power chains. The study design involved standardized preparation, temperature-controlled immersion, tensile force measurements, and subsequent statistical analysis to derive comparative results. A total of twenty continuous-type orthodontic power chain specimens were used in this study. Each specimen measured 14 mm in length, corresponding to five lumens. The samples were obtained from the same brand and batch to ensure uniformity in material properties and eliminate variability. The specimens were equally divided into four experimental groups, each consisting of five samples (n = 5), based on the temperature conditions to which they were exposed (Figure 1-2).

Figure 1. Orthodontic Power Chain

Grouping Based on Temperature Conditions

The specimens were categorized into the following four groups (Figure 2.):

- Group A (Cold exposure): Immersed in water maintained at 5°C, simulating the effect of exposure to cold beverages.
- Group B (Room temperature control): Immersed in water at 25°C, representing standard room temperature conditions and serving as the control group.
- Group C (Oral temperature simulation): Immersed in water maintained at 37°C, closely simulating intraoral physiological temperature.
- Group D (Hot exposure): Immersed in water at 60°C, simulating conditions akin to the consumption of hot beverages such as tea or coffee.

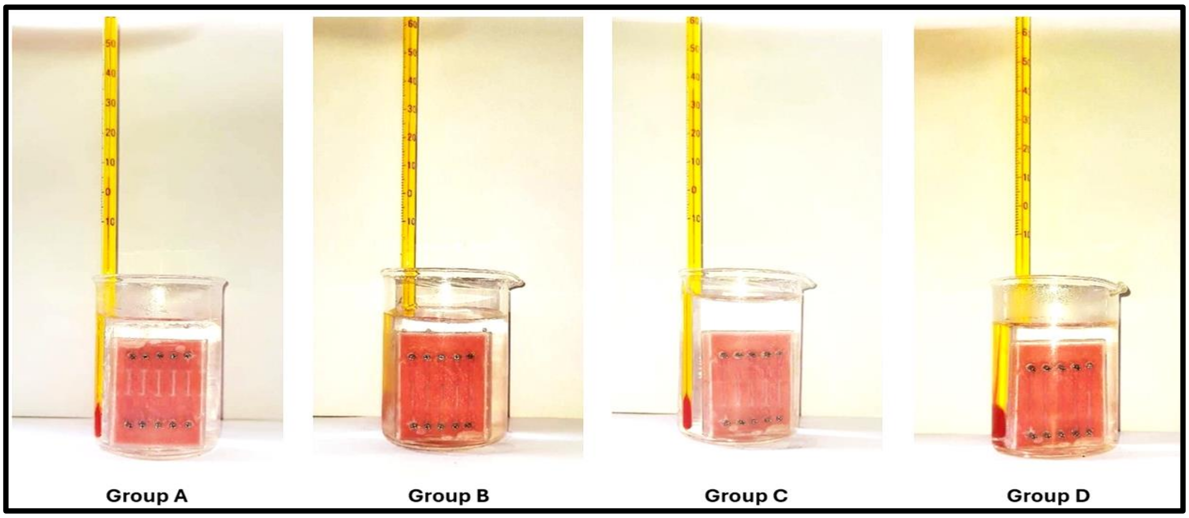


Figure 2. Grouping based on temperature conditions

Temperature Maintenance and Immersion Protocol

Each group of specimens was immersed in distilled water (pH 7.0) maintained at the specified temperature. The temperature conditions were achieved using the following equipment and techniques:

- 5°C: Achieved using a refrigerated cooling unit.
- 25°C: Maintained at ambient room temperature.
- 37°C: Sustained using a laboratory incubator.
- 60°C: Maintained using a thermostatically controlled hot plate.

The immersion duration for each group was fixed at 140 minutes, calculated based on the assumption of twice-daily exposure to hot or cold fluids, each lasting approximately five minutes, over a standard 14-day power chain usage cycle. This was designed to replicate a realistic consumption pattern and simulate cumulative intraoral exposure to temperature variations.

Measurement of Tensile Force

The tensile force of each specimen was measured before and after immersion using a Dontrix gauge (Tensiometer), a reliable tool for assessing orthodontic force levels. The force measurement procedure was standardized as follows:

1. The first lumen of each power chain specimen was securely tied to a fixed acrylic plate using a strong dental thread.
2. The last lumen was hooked onto the arm of the Dontrix gauge.
3. The chain was gradually stretched until it reached 28 mm, which represented a 100% elongation from its original unstretched length (14 mm).
4. The force exerted at this elongation was recorded in gram-force (gf) units, as displayed on the Dontrix gauge dial, under the "gram/pond" section.

For each sample, two tensile force readings were obtained:

- Initial force: Measured prior to immersion.
- Final force: Measured after the immersion process followed by stretching to 28 mm.

The percentage decrease in tensile force was calculated using the following formula:

$$\text{\% Decrease in tensile force} = \frac{\underline{(\text{Initial force} - \text{Final force})}}{\text{Initial force}} \times 100$$

This formula allowed for quantifying the force degradation of each power chain under different thermal exposures.

Statistical Analysis

The collected data were tabulated and subjected to statistical analysis to assess the significance of temperature-related variations in force degradation. Descriptive statistical analysis was performed by calculating the mean and standard deviation (SD) for each experimental group. The data were first evaluated for normality of distribution. Subsequently, a one-way analysis of variance (ANOVA) was employed to compare the mean percentage reduction in tensile force across the four

temperature groups. The statistical computations were performed using the online One-way ANOVA calculator provided by Social Science Statistics (www.socscistatistics.com). ANOVA was selected due to its ability to detect statistically significant differences between more than two independent groups. A p-value of less than 0.05 was considered statistically significant, indicating that temperature conditions had a notable impact on the force degradation behaviour of the power chains.

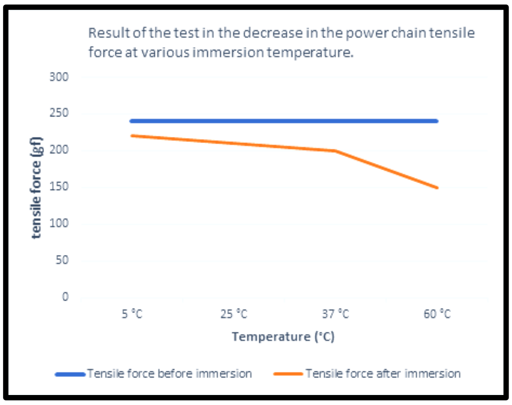
Results

This in-vitro study examined how different temperature conditions influence the tensile strength of orthodontic elastomeric power chains. The specimens were immersed in water at controlled temperatures of 5°C, 25°C, 37°C, and 60°C, after which the tensile force was measured and compared to the initial pre-immersion force. Each group exhibited a measurable decrease in tensile force, indicating that thermal exposure had a direct impact on the mechanical properties of the elastomeric chains. The summary of findings is presented in Table 1.

Table 1. Decrease in power chain tensile strength following exposure to different temperatures

Immersion medium	Immersion temperature (°C)	Tensile force Before immersion (gf)	Tensile force After immersion (gf)	Force reduction (%)
Water	05°C ± 2	240 ± 5	220 ± 5	08 ± 1.3
	25°C ± 2	240 ± 5	210 ± 5	12 ± 1.5
	37°C ± 2	240 ± 5	200 ± 5	18 ± 1.5
	60°C ± 5	240 ± 5	150 ± 5	38 ± 0.5

Across all groups, the initial tensile force before immersion was standardized at 240 ± 5 gf, ensuring uniform baseline conditions for comparison. Following immersion and 100% elongation (from 14 mm to 28 mm), a notable decrease in tensile force was observed in every treatment group. Additionally, a 4 mm elongation from the original length was consistently recorded across all specimens, signifying thermal-induced deformation alongside force degradation. The lowest force degradation was observed in Group A (5°C), with a reduction of only 8 ± 1.3%, suggesting that exposure to cold temperatures had minimal adverse effect on the chain’s elasticity. In contrast, Group D (60°C) demonstrated the highest force degradation, with a significant 38 ± 0.5% reduction in tensile strength, indicating that high-temperature exposure severely compromises the force-retention capabilities of the elastomeric chains. Intermediate reductions were observed in Group B (25°C) and Group C (37°C), with force losses of 12 ± 1.5% and 18 ± 1.5% respectively. This progressive pattern suggests a temperature-dependent degradation, where the extent of force loss increases proportionally with the rise in immersion temperature. The results also indicate that the effect of thermal exposure is statistically significant. A homogeneity test confirmed that data variations within groups were consistent, validating the use of one-way ANOVA for further analysis. The ANOVA test revealed a statistically significant difference ($P < 0.05$) among the temperature treatment groups, confirming that temperature variations had a measurable and distinct effect on the tensile force degradation of orthodontic power chains. These findings underscore the importance of considering thermal influences in clinical practice, particularly in regions where patients may be exposed to extreme hot or cold dietary habits. The data suggest that hot beverages or elevated intraoral temperatures may significantly reduce the mechanical efficiency of elastomeric chains, potentially affecting treatment outcomes if replacement intervals are not adjusted accordingly.



Discussion

The present in-vitro study evaluated the effect of temperature variations on the tensile strength of orthodontic elastomeric power chains. The findings demonstrated that exposure to different thermal conditions significantly affected the mechanical properties of the power chains, with greater temperature associated with increased degradation of tensile force. Power chains that began with a uniform tensile force of 240 ± 5 gram-force (gf) showed progressive reductions when immersed in water at 5°C, 25°C, 37°C, and 60°C, resulting in final tensile forces of 220 ± 5 gf, 210 ± 5 gf, 200 ± 5 gf, and 150 ± 5 gf, respectively. These changes corresponded to force reductions of 8%, 12%, 18%, and 38%, indicating a temperature-dependent degradation trend. The difference in tensile force across the temperature treatment groups was statistically significant ($P < 0.05$), affirming the direct impact of temperature on the mechanical behaviour of elastomeric materials. The mechanical degradation of elastomeric chains over time can be attributed to their viscoelastic and thermoplastic nature, as they are composed primarily of polyurethane polymers. Upon stretching, the power chain experiences structural bond elongation and molecular rearrangement. The initial stretching typically causes a temporary change due to the rapid realignment of structural bonds. However, with sustained or repeated stretching, permanent deformation occurs as the polymer network becomes fatigued and the structural bonds undergo irreversible changes[7]. This explains why even in the short 140-minute simulated immersion, notable force loss was evident. Our findings align with Syaukani's 2011 study, which concluded that the greatest force degradation in elastomer chains occurs within the first 24 hours, followed by a gradual and consistent decline in subsequent days[8].This aligns with clinical observations indicating that although power chains provide effective force initially, their strength reduces over time, requiring periodic replacement to maintain adequate orthodontic force levels. Temperature is a critical factor influencing this degradation. The present study observed the least force loss at 5°C (8%), which can be explained by reduced molecular mobility at lower temperatures. Cooling causes the polymer structure to harden, maintaining stiffness and resisting elongation. On the contrary, at 60°C, the most substantial degradation (38%) occurred, consistent with the behaviour of thermoplastic polymers under thermal stress. At elevated temperatures, such as those simulated for hot beverage consumption; the increased molecular movement weakens secondary bonds, softens the polymer matrix, and accelerates polymer chain relaxation, resulting in rapid force decay. This temperature-sensitive behaviour is supported by earlier findings by Taloumis et al. (1997), who reported that elastomeric chains lose up to 53–68% of their force within 24 hours when exposed to elevated intraoral temperatures[5]. Similarly, Nattrass (1998) highlighted that elastomer chains subjected to increasing temperatures display reduced tensile strength, further supporting our results[2]. At 37°C, which mimics average intraoral temperature, force degradation was recorded at 18%, confirming that even standard oral conditions can cause clinically relevant reductions in force. Although less severe than high-temperature exposures, this gradual decline reinforces the need for orthodontists to consider replacement intervals and force calibration during routine adjustments. These changes can be attributed to the molecular composition and structural properties of polyurethane. As a thermoplastic material, polyurethane becomes softer with heat and harder when cooled. At elevated temperatures, the polymer chains gain kinetic energy, enabling greater freedom of movement, which compromises elasticity and leads to loss of tensile strength. Conversely, low temperatures restrict molecular motion, thereby enhancing material stiffness and resistance to deformation. From a clinical perspective, these findings are significant. Daily habits such as the frequent consumption of hot beverages (e.g., tea, coffee) can exacerbate force decay, potentially requiring more frequent power chain replacement to maintain desired orthodontic force levels. Conversely, exposure to cold beverages may help preserve chain elasticity but may not significantly enhance clinical efficiency. Nevertheless, understanding these thermally induced changes can

help orthodontists make informed decisions regarding material selection, replacement timing, and patient instructions. Furthermore, advising patients about dietary habits, especially in cases involving long intervals between appointments or when maintaining optimal force is critical (e.g., space closure or anchorage control), becomes increasingly important. Incorporating temperature awareness into patient education may serve as a valuable adjunct to improving treatment outcomes.

Conclusion

The findings of this study clearly demonstrate that temperature plays a critical role in influencing the tensile force levels of orthodontic elastic chains. Specifically, elevated temperatures, such as 60°C, result in a significantly greater degradation of force over time when compared to lower temperatures like 5°C. This temperature-dependent force decay underscores the importance of considering environmental and intraoral temperature fluctuations during orthodontic treatment planning. Given these results, it is imperative for orthodontists to educate patients about the potential impact of thermal exposure on the performance of elastic chains. Patients should be advised to avoid frequent intake of hot foods and beverages that may contribute to accelerated force degradation. Moreover, tailored dietary recommendations should be provided to help preserve the mechanical properties of elastomeric materials throughout the course of treatment. Incorporating such preventive strategies can contribute to more consistent force application, thereby improving overall treatment efficiency and outcomes.

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