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The Effects of Activated Carbon Toothpastes on Orthodontic Elastomeric Chains—An In Vitro Study

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Abstract: Objectives: Using toothpaste with activated carbon might increase the decay of orthodontic elastomeric chains' (ECs) tensile strength, thereby compromising orthodontic treatment. Therefore, this study aimed to evaluate the influence of activated charcoal toothpaste on orthodontic ECs. Materials and Methods: A total sample of 180 EC segments from 3M Unitek®, Ormco® and Ortho Classic® brands were equally divided into 12 groups, each comprising 15 specimens. These pieces were kept in artificial saliva at 37 °C and brushed twice daily for 28 days, with three distinct types of toothpaste: Colgate® Total, Colgate® Max White, and Dr Organic® Extra Whitening Charcoal Toothpaste. The latter two toothpastes contain activated charcoal. Tensile strength, resistance to rupture and colour variation were evaluated at time zero and day 28. Descriptive statistics, one-way ANOVA and Tukey HSD tests were performed at $p \leq 0.05$. Results: Toothpaste with and without activated carbon significantly reduced the tensile strength and resistance to rupture of the ECs, and altered EC colour ($p < 0.0001$). There was inconsistency in the effect of the activated carbon on EC characteristics, most probably due to the different compositions of the ECs and percentages of whitening agents in the toothpastes. Conclusions: The material composition of ECs contributes to their tensile strength decay, resistance to rupture and colour change over time. The variable percentage of activated carbon in a toothpaste likely underlies the different effects observed, depending on the EC brand. Clinical Relevance: It might be reasonable to advise patients wearing ECs to avoid using toothpaste with activated carbon until further evidence becomes available.

Keywords: active carbon toothpaste; elastomeric chains; rupture point; tensile strength; colour change

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1. Introduction

Elastomeric chains (ECs) are amorphous polyurethane-based polymers that exhibit the properties of both rubber and plastic, both of which account for their elasticity [1]. The form, colour, shape memory, flexibility, low cost, and ease of handling of ECs have resulted in their extensive incorporation into orthodontic practice in recent decades [2,3]. However, despite the favourable characteristics of ECs, their ageing pattern and mechanical efficiency are marked by a quick onset of intra-oral maturation, leading to a loss in strength of 50–75% over time [4,5], causing alterations in the force they apply to teeth from a continuous pattern to an interrupted form [3].

It is generally recognized that a fixed orthodontic apparatus offers favourable sites for microorganism colonization and plaque retention, which might cause enamel demineralization and periodontal disease [3,6]. ECs, specifically, might enhance bacterial plaque colonization due to their latex component's rough surface and absorption characteristics [7].

Therefore, it is recommended that a customized oral hygiene care protocol be implemented, including brushing teeth with effective toothpaste and use of mouthwashes [7].

Numerous types of toothpaste have been developed and introduced onto the market. Nearly all contemporary toothpaste includes essential elements such as thickening agents, flavour, surfactants, water and specific agents that benefit consumer needs. These benefits include whitening teeth, improving gingival care, reducing tooth sensitivity, freshening breath and increasing enamel resistance to the risk of caries [8,9].

There has been an increase in both the demand for and supply of whitening toothpaste containing activated carbon [8,9]. This abrasive component removes and prevents the formation of external enamel pigments but can be excessively abrasive due to the particles' size [10,11]. Throughout fixed orthodontic treatment, tooth enamel is frequently more susceptible to stains, leading patients to use whitening instead of conventional toothpaste to regain tooth brightness. Dental plaque and discolouration are removed from teeth through a three-component scheme consisting of the toothbrush bristles, enamel tooth surface and the activated carbon abrasive particles in between [12,13]. The mechanical action of brushing bonded teeth wearing auxiliary ECs might increase the decay of the ECs' tensile strength, compromising orthodontic treatment [14]. Other local considerations might exacerbate the impact of toothpaste, such as the number and shape of toothbrush bristles, as well as the frequency of brushing and brushing technique [15,16]. Numerous investigations confirmed that active carbon toothpaste is highly absorbent and can exchange ions across nanopores, adhere to enamel and remove stains by absorbing pigments from the tooth enamel surface [15–18]. A search of the published literature found only two studies exploring the impact of activated carbon on ECs [5,14]. Behnaz et al. [14] concluded that toothpaste with whitening agents significantly reduces EC tensile strength compared to non-whitening toothpaste. However, their investigation used only one type of EC (3M Unitek®, 3M Unitek Corporation, Monrovia, CA, USA). In another study, Pithon et al. [5] observed a similar degrading effect of two of the most widely used whitening mouthwashes (Plux and Listerine) on an EC manufactured by Morelli (Sorocaba, Brazil). Furthermore, according to our search, none of the studies investigated the impact of activated carbon toothpaste on the EC rupture point or colour stability. Therefore, this study aimed to evaluate the effect of toothpaste containing activated carbon on the force degradation of different brands of orthodontic ECs. A further aim was to evaluate the effect of these whitening toothpastes on the EC rupture point and their colour stability. Within this context, the following null hypotheses were tested:

1. The presence or absence of activated carbon agents in toothpaste has a similar effect on EC tensile strength degradation over time;
2. The presence or absence of activated carbon agents in toothpaste has a similar effect on the EC rupture point over time;
3. The presence or absence of activated carbon agents in toothpaste similarly affects the EC colour stability.

2. Materials and Methods

This was an experimental invitro study undertaken at the Egas Moniz School of Health and Science—Instituto Universitário Egas Moniz (IUEM). The investigation was approved by the Scientific Committee of IUEM.

2.1. Sample Size

Based on the results of a previous study [14] and considering a 5% significance level and a 95% power, a minimum of 12 segments of each of the three examined ECs was determined to be necessary. This was increased to 15 to compensate for any losses during the experimental procedure.

2.2. Sample Preparation

A total of 180 pieces of transparent closed-type ECs were prepared, comprising three brands: 3M Unitek®, 3M Unitek Corporation, Monrovia, CA, USA, Ormco® (Orange, Ca, USA) and Ortho Classic® Orthodontics (McMinnville, OR, USA). There were 60 specimens of each brand divided into four groups, resulting in 15 specimens in each group. One group of each brand was tested before starting the experiment to determine the baseline (day zero) tensile strength, resistance to rupture and colour, while the other three groups of each brand were included in the experiment. The length of each segment was based on the number of modules included in each specimen. There were four modules in each segment, corresponding to 8.5 mm for 3M Unitek®, 9.0 mm for Ormco® and 9.5 mm for Ortho Classic®.

2.3. Acrylic Plates

Three customized acrylic plates were fabricated. Each plate was 24 cm in length and 3 cm wide, and 90 welded steel pins (1 mm in diameter) were mounted in two parallel lines, making it possible to place 45 ECs on each plate, 15 from each brand, 5 mm apart (Figure 1). The distance between the two parallel rows was designed to allow a 50% stretching of the ECs of the three brands (3M Unitek®, 12.75 mm; Ormco®, 13.5 mm; and Ortho Classic®, 14.25 mm). The three plates were then categorized into three equal groups, each brushed twice daily as follows: Group 1 (G1) with Colgate® Total Original (New York, NY, USA) toothpaste (activated carbon-free); Group 2 (G2), Colgate® Max White Charcoal (New York, NY, USA) toothpaste; and Group 3 (G3) Dr Organic® Extra Whitening (Llansamlet, Wales) toothpaste (the latter two contained activated carbon). One operator undertook all the experiments to minimize possible human error.

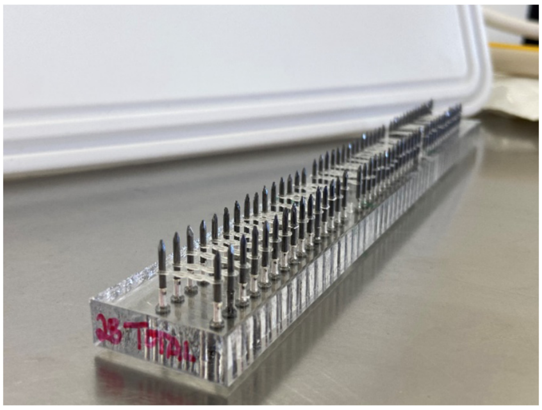

Figure 1. Acrylic plate used for stretching the elastic chains used in the experiment.

The mounted acrylic plates were then immersed in artificial saliva at 37 °C (±1 °C) and stored for the duration of the experiment (28 days) in a universal incubator (Memmert® INE 4002, Memmert GmbH, Schwabach, Germany). To simulate the effects of daily toothpaste use, the same operator performed the brushing by applying a quantity of 0.4 mm of the designated toothpaste in each brushing cycle using a syringe. Before returning the specimens to the incubator, the plates were washed with running water for 30 s to remove any remaining toothpaste from the ECs. This step was repeated daily throughout the experiment (28 days). The EC tensile strength, resistance to rupture and colour stability were evaluated on day 28.

2.4. Determination of the Tensile Strength

The tensile strength was measured using a calibrated Autograph AG-IS14 Universal Testing Machine (Shimadzu, Kyoto, Japan). The test was performed by attaching one end of the EC segment to a post fixed by a screw to a jig, while placing the other end of the EC on a second identical post on the same jig. Subsequently, the EC was stretched by 50% of its length and the force delivered was recorded in Newtons (N).

2.5. Determination of the Resistance to Rupture

The resistance to rupture of each EC was assessed using an AG-IS Universal Kit (Shimadzu). Each specimen was attached firmly to two jigs on the machine and the test was performed by stretching the examined specimen at a constant velocity of 100 mm/min until the rupture point was reached.

2.6. Determination of Colour Stability

The colour stability in each EC specimen was evaluated using a spectrophotometer, the SpectroShade Micro 15 (Medical High Technologies, Bad Krozingen, Germany), with a CIE L*a*b* system. The CIE L*a*b* system consists of three colour coordinates: L*, lightness (–L* = black; ±L* = white); a*, green–red (–a* = green; ±a* = red); and b*, blue–yellow (–b* = blue; ±b* = yellow). The magnitude of the total colour difference (between day zero and after brushing on day 28) was represented by a single number ΔE, where $\Delta E = [(\Delta L^*)^2 \pm (\Delta a^*)^2 \pm (\Delta b^*)^2]^{1/2}$ and ΔE is the result of the chromatic difference of each coordinate. Thus, $\Delta L^* = L^*$ final − L^* initial; $\Delta a^* = a^*$ final − a^* initial; and $\Delta b = b^*$ final − b^* initial. For colour determination, the total sample was placed on a white base under the same measurement conditions. This white base was located inside a black box to avoid possible effects of light in the environment. Prior to recording the results, the device was calibrated following the manufacturer's recommendations. The assessment of colour was performed on day zero and day 28.

2.7. Statistical Analysis

Statistical analysis was performed using the IBM® SPSS Statistics package v. 290. Descriptive statistics (mean and standard deviation (SD)) were computed for the experimental outcomes, considering the differences in tensile strength, rupture point and colour change. Inferential comparison of mean values was performed by one-way ANOVA followed by Tukey's and Duncan's post hoc tests. A significance level of 5% ($p \leq 0.05$) was established for all inferential analyses.

3. Results

3.1. Baseline Discrepancy between the Three Brands of ECs

Table 1 displays the mean values and SD of the baseline tensile strength of the three EC brands recorded on day zero (when the ECs were stretched by 50% of their original length). The ANOVA revealed significant differences in the mean values of tensile strength ($p = 0.003$) and resistance to rupture ($p < 0.001$) between the three brands of ECs before using any toothpaste ($p \leq 0.003$). Duncan's multiple range post hoc test showed that the Ortho Classic® EC (3.717 ± 0.11 N) had a tensile strength significantly greater than the 3M Unitek® (3.287 ± 0.14 N) and Ormco® (3.327 ± 0.09 N) EC brands. Furthermore, Tukey's HSD post hoc test revealed a significant difference in the resistance to rupture between the ECs of the three brands in the following order: Ormco® (42.628 ± 0.213 mm), 3M Unitek® (36.352 ± 0.604 mm), and Ortho Classic® (31.323 ± 0.210 mm).

Table 1. Mean values and standard deviation for three tested elastic chain (EC) brands of tensile strength (ΔTS) (N) (stretched for 50%) on day zero and day 28 following exposure to different toothpastes. The percentage of the declining tensile strength at each time is also presented (15 EC specimen, per group).

EC Brand	t0	Toothpaste	t28	ΔTS (t28 − t0)	Loss %
3M Unitek®	3.287 ± 0.143	Colgate Total®	1.448 ± 0.014	−1.84 ^{b,c} (±0.55)	−55.93
		Colgate Max White®	1.484 ± 0.026	−1.80 ^{b,c} (±0.56)	−54.86
		Dr Organic®	1.406 ± 0.014	−1.88 ^{a,b,c} (±0.58)	−57.23

Table 1. *Cont.*

EC Brand	t0	Toothpaste	t28	ΔTS (t28 − t0)	Loss %
Ormco®	3.327 ± 0.092	Colgate Total®	1.718 ± 0.021	−1.61 ^{c} (±0.35)	−48.37
		Colgate Max White®	1.739 ± 0.030	−1.59 ^{c} (±0.38)	−47.73
		Dr Organic®	1.584 ± 0.013	−1.74 ^{b,c} (±0.37)	−52.39
Ortho Classic®	3.717 ± 0.111	Colgate Total®	1.454 ± 0.017	−2.26 ^{a,b} (±0.40)	−60.89
		Colgate Max White®	1.318 ± 0.018	−2.40 ^{a} (±0.45)	−64.54
		Dr Organic®	1.543 ± 0.038	−2.17 ^{a,b} (±0.50)	−58.48

Multiple mean post hoc comparison through Tukey HSD test: different letters indicate significant different mean ΔTS values ($p < 0.05$). t0 before starting the experiment and t28 is at the end of the experiment.

3.2. Tensile Strength Assessment within and between Groups on Day 28

For the ECs in all groups, there were significant losses in tensile strength, with the mean value approaching 50% or more of their initial strength on day zero ($p < 0.001$), with significant differences between brands. Thus, Ortho Classic® showed the greatest drop in tensile strength (ranging from 58.48% to 64.54%), followed by 3M Unitek® (ranging from 54.86% to 57.23%) and lastly, Ormco® (ranging from 47.73% to 52.39%). A Tukey HSD post hoc test revealed that the type of toothpaste used did not significantly influence the strength loss within each of the EC brand groups over time, except in the case of Ortho Classic® ECs brushed with Colgate Max White® toothpaste, which lost a mean value of 64.54% of its strength compared to the strength decay when exposed to Colgate Total® (60.89%) and Dr Organic® (58.48%) (Table 1).

3.3. Rupture Point Assessment within and between Groups on Day 28

Significant differences were observed in the mean values of resistance to rupture within each group of the three EC brands between day zero and day 28 ($p < 0.001$). A Tukey HSD post hoc test revealed that the type of toothpaste used did not significantly affect the value of the rupture point across the EC groups over time ($p = 0.195$), except for the Ormco® EC group brushed with Dr Organic® Extra White toothpaste (which showed a loss of 10.49%). This was significantly different ($p < 0.001$) from the other eight groups (Table 2).

Table 2. Changes in the elastic chain (EC) resistance to rupture (rupture point) (ΔRP) between day 0 (t0) and day 28 (t28). Values presented as means (± standard deviation), (15 EC specimen, per group).

EC Brand	T0	Toothpaste	T28	ΔRP (t28 − t0)	Lose %
3M Unitek®	36.352 ± 0.604	Colgate Total®	35.674 ± 0.309	−0.68 ^{b} (±2.35)	−1.87
		Colgate Max White®	35.517 ± 0.264	−0.84 ^{a,b} (±2.40)	−2.30
		Dr Organic®	36.343 ± 0.232	−0.01 ^{b} (±2.61)	−0.63
Ormco®	42.628 ± 0.213	Colgate Total®	42.782 ± 0.643	0.15 ^{b} (±2.46)	±0.36
		Colgate Max White®	41.604 ± 0.663	−1.02 ^{a,b} (±2.46)	−2.4
		Dr Organic®	38.155 ± 1.885	−4.47 ^{a} (±7.47)	−10.49
Ortho Classic®	31.323 ± 0.210	Colgate Total®	31.945 ± 0.138	0.62 ^{b} (±0.81)	±1.98
		Colgate Max White®	31.404 ± 0.187	0.08 ^{b} (±1.34)	±0.26
		Dr Organic®	31.907 ± 0.214	0.58 ^{b} (±1.32)	±1.86

Multiple mean post hoc comparison through Tukey HSD test: different letters indicate significant different mean ΔRP values ($p < 0.05$). t0 before starting the experiment and t28 is at the end of the experiment.

3.4. Evaluation of Colour Change within and between Groups on Day 28

There was a significant colour change within each EC group over time: Dr Organic Extra Whitening toothpaste had a significantly greater colour-alteration effect on Ormco® and Ortho Classic® ECs compared to the other groups brushed with Colgate Total® and

Colgate® Max White and to the 3M Unitek® ECs cleaned with Dr Organic® Extra Whitening toothpaste (Table 3).

Table 3. Elastic chain (EC) colour change (ΔE) between day 0 (t0) and day 28 (t28). Values presented as means (±standard deviation), (15 EC specimen, per group).

EC Brand	Toothpaste	ΔE (t28 − t0)	Min.–Max.
3M Unitek®	Colgate Total®	0.67 [a] (±0.48)	0.14–1.71
	Colgate Max White®	0.66 [a] (±0.48)	0.22–1.91
	Dr Organic®	0.92 [a] (±0.69)	0.14–2.79
Ormco®	Colgate Total®	1.47 [a,b] (±1.00)	0.14–3.26
	Colgate Max White®	2.06 [a,b] (±1.15)	0.77–5.09
	Dr Organic®	2.55 [b] (±1.16)	1.16–4.74
Ortho Classic®	Colgate Total®	1.87 [a,b] (±1.99)	0.30–7.72
	Colgate Max White®	1.55 [a,b] (±1.93)	0.14–6.24
	Dr Organic®	2.66 [b] (±2.10)	0.66–6.98

Multiple mean post hoc comparison through Tukey HSD test: different letters indicate significant different mean ΔE values ($p < 0.05$). t0 before starting the experiment and t28 is at the end of the experiment.

4. Discussion

ECs are frequently used for force transmission during orthodontic treatment. Numerous investigations have examined the mechanical impact of intraoral environmental factors on the degradation of EC tensile strength over time [2,3,19]. The growing interest globally in using whitening toothpaste has necessitated investigating the effect of whitening components on EC characteristics.

The in vitro design of the present investigation offered the possibility of evaluating one covariate at a time (in this case, activated carbon) and avoiding the influence of other components present in the oral cavity, such as pigmentation caused by food and drink [20,21]. However, despite the previously reported advantages, an in vitro study design falls short in simulating the oral environment, which includes enzymes, pH variation, natural microflora and temperature fluctuation. Therefore, it is imperative to exercise caution when generalizing the outcomes of such investigations to clinical circumstances [20,21].

Throughout this investigation, the ECs were always stretched to a fixed distance between the pins installed on the acrylic plates without simulating the tooth movement that occurs during oral function. This might have affected the experimental outcome [14], and therefore, it is recommended that a randomized clinical trial be undertaken to further explore EC behaviour in a clinical setting.

Numerous laboratory-based investigations have reported the decay of EC strength over time [2,4,19,22–26]. Rock et al. [23]. concluded that only 43–52% of the initial EC tensile strength was maintained in a simulated oral cavity environment following four weeks of use, while an EC group maintained in air retained 70–75% of the initial elasticity. However, different brands of EC show dissimilar effectiveness [24,25]. This discrepancy might be attributed to processing variations and the different dimensional and morphological structures adopted [4,25].

The duration of the present experiment was 28 days, which is the average interval between clinical consultations in an orthodontic clinical setting. In line with the above findings in the literature, our study revealed significant discrepancies over time in the mechanical properties of three of the most popular EC brands in orthodontics (3M Unitek®, Ormco® and Ortho Classic®) following brushing with various toothpastes.

One consistent result in our study was that toothpaste, both with and without activated carbon, had a comparable effect on the degradation of strength of 3M Unitek® and Ormco® ECs. It should be noted that of the three EC brands, Ormco® lost the least tensile strength, while Ortho Classic® lost the most, regardless of the toothpaste used, with the highest tensile strength on day zero and the lowest on day 28. Ortho Classic® EC showed more significant tensile strength degradation with all three toothpastes than the 3M Unitek® and Ormco® EC groups. However, the Ortho Classic® EC tensile strength degradation was significantly higher when brushed with Colgate Max White® compared to brushing with Colgate and Dr Organic® toothpastes (third null hypothesis rejected). The difference in the behaviour of Ortho Classic® EC compared to 3M Unitek® and Ormco® EC groups over time seems to be related to the materials constituting the ECs and not to extrinsic factors.

A similar, earlier in vitro investigation by Behnaz et al. [14] concluded that tensile the strength degradation of ECs brushed with Crest® and Sensodyne® whitening toothpastes was greater than that of their control groups over time. However, the investigators used only one type of EC (3M Unitek®), and the brands of whitening toothpastes used were different from ours. Also, in another study, Pithon et al. [5] found similar degrading effects resulting from two of the most widely used whitening mouthwashes (Plux and Listerine) on an EC manufactured by Morelli (Sorocaba, Brazil). Nevertheless, a direct comparison between the previous and present studies is compromised by the heterogeneity of the materials used.

Our experiments show significant inherent discrepancies in the resistance to rupture among the three EC brands, with the Ormco® ECs being significantly more resistant before exposure to external elements. This resistance to rupture was significantly lower on day 28 in all groups. The activated carbon contained in the toothpastes did not significantly affect the value of the rupture point over time, except for Ormco® ECs, where the group brushed with Dr Organic® Extra White toothpaste had significantly weakened resistance to rupture compared to the groups exposed to Colgate Max White® toothpaste, which contains activated carbon, and Colgate Total® toothpaste, which does not (second null hypothesis rejected).

Transparent ECs have improved the aesthetic aspect of fixed orthodontic appliances. However, ECs are prone to discolouration due to their intrinsic components and the effects of extrinsic factors. Aldrees et al. [26] indicated a reference value of 3.3 ΔE as the threshold for a clinically visible and relevant colour discrepancy. None of the ECs tested reached this level of discolouration. Our investigation concluded that toothpastes altered the EC colour similarly, except for the significantly greater discolouring impact of Dr Organic® Extra Whitening toothpaste on the Ormco® and Ortho Classic® brands of ECs (third null hypothesis rejected); 3M Unitek® ECs were not affected in this way. This discolouration was not observed with Colgate Max White® toothpaste, which also contains activated carbon, possibly due to the different levels of activated carbon approved by each manufacturer.

This study indicates that the type of EC material used contributes to their strength decay and resistance to rupture over time. The tensile strength of Ortho Classic® ECs was the most significantly degraded, regardless of the toothpaste used, compared to the other EC brands. Further in vivo studies are recommended to gain a complete understanding of the elastomeric behaviour of more brands of ECs in the oral cavity, but we were able to show that activated carbon toothpastes have different effects on ECs over time, probably depending on their different compositions. Dr Organic® Extra Whitening toothpaste, which contains activated carbon, significantly weakened the rupture point and altered the colour of Ormco® and Ortho Classic® ECs. Given that the two toothpastes containing activated carbon did not have similar effects, it might be reasonable to advise patients wearing ECs to avoid using toothpastes with bleaching agents when using ECs until further evidence becomes available.

Toothpastes containing activated carbon are relatively new in the market, and few studies have been carried out to investigate their effect on dental materials. Therefore, further research is required. In particular, it would be interesting to evaluate the effect of other whitening toothpastes available in the market on the intrinsic characteristics of the available EC brands.

5. Conclusions

- There are significant discrepancies in tensile strength, rupture point and colour between the three EC brands tested, both before and after their exposure to any toothpaste;
- The material composition of each brand of EC contributes to its strength decay, resistance to rupture and colour change over time;
- The percentage of activated carbon in a toothpaste may be responsible for the variable effects on each brand of EC.

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Conflicts of Interest: Author Mariana Isidro Do Carmo was employed by the company The Libyan Authority for Scientific Research. The remaining authors declare that the re-search was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Yagura, D.; Baggio, P.; Carreiro, L. Deformation of elastomeric chains related to the amount and time of stretching. *Dental Press. J. Orthod.* **2013**, *18*, 136–142. [CrossRef] [PubMed]
2. Santos, A.; Tortamano, A.; Naccarato, S. An in vitro comparison of the force decay generated by different commercially available elastomeric chains and NiTi closed coil springs. *Braz. Oral. Res.* **2007**, *21*, 51–57. [CrossRef] [PubMed]
3. Mirhashemi, A.; Saffarshahroudi, A.; Sodagar, A.; Atai, M. Force-degradation pattern of six different orthodontic elastomeric chains. *J. Dent.* **2012**, *9*, 204.
4. Eliades, T.; Bourauel, C. Intraoral aging of orthodontic materials: The picture we miss and its clinical relevance. *Am. J. Orthod. Dentofac. Orthop.* **2005**, *127*, 403–412. [CrossRef]
5. Pithon, M.; Macena, J.; Prado, M. Effects of active substances in dentifrices on force degradation of elastomeric chain elastics. *J. Indian. Orthod. Soc.* **2014**, *48*, 27–32. [CrossRef]
6. Bachiega Morelli, R.F.; Nelson-Filho, P.; Carpio Horta, K.; Feres, M.; Lima Ferreira, J.T.; Romano, F.L.; Stuani, M.B.S.; Saraiva, M.C.P.; Reis, C.L.B.; Matsumoto, M.A.N. Microbial contamination profile on esthetic elastomeric ligatures through the checkerboard DNA–DNA hybridization technique: A randomized split-mouth study. *J. Orofac. Orthop.* **2024**, *85*, 1–10. [CrossRef] [PubMed]
7. Braga, E.; Souza, G.; Barretto, P.; Ferraz, C.; Pithon, M. Experimental Evaluation of Strength Degradation of Orthodontic Chain Elastics Immersed in Hot Beverages. *J. Indian Orthod. Soc.* **2019**, *53*, 244–248. [CrossRef]
8. Vaz, V.; Jubilato, D.; Oliveira, M.R.M.; Bortolatto, J.F.; FlorOs, M.C.; Dantes, A.A.R.; Oliveira Junior, O.B.D. Whitening toothpaste containing activated charcoal, blue covarine, hydrogen peroxide or microbeads: Which one is the most effective? *J. Appl. Oral. Sci.* **2019**, *27*, e20180051. [CrossRef]
9. Franco, M.; Uehara, J.; Meroni, B.; Zuttion, G.; Cenci, M. The effect of a charcoal-based powder for enamel dental bleaching. *Oper. Dent.* **2020**, *45*, 618–623. [CrossRef]
10. Pertiwi, U.; Eriwati, Y.; Irawan, B. Surface changes of enamel after brushing with charcoal toothpaste. *J. Phys. Conf. Ser.* **2017**, *884*, 12002. [CrossRef]
11. Brooks, J.; Bashirelahi, N.; Reynolds, M. Charcoal and charcoal-based dentifrices: A literature review. *J. Am. Dent. Assoc.* **2017**, *148*, 661–670. [CrossRef]
12. Muntean, A.; Sava, S.; Delean, A.G.; Mihailescu, A.M.; Dumitrescu, L.S.; Moldovan, M.; Festila, D.G. Toothpaste composition effect on enamel chromatic and morphological characteristics: In vitro analysis. *Materials* **2019**, *12*, 2610. [CrossRef] [PubMed]
13. Hattab, F.N.; Qudeimat, M.A.; AL-Rimawi, H.S. Dental discoloration: An overview. *J. Esthet. Restor. Dent.* **1999**, *11*, 291–310. [CrossRef] [PubMed]
14. Behnaz, M.; Dalaie, K.; Hosseinpour, S.; Namvar, F.; Kazemi, L. The effect of toothpastes with bleaching agents on the force decay of elastomeric orthodontic chains. *Eur. J. Dent.* **2017**, *11*, 427–431. [CrossRef]

15. Huaman-Sarmiento, E.; Mayta-Tovalino, F.; Munive-Degregori, A.A.; Mendoza, R.; Barja-Ore, J.; Mauricio-Vilchez, C. Uses and applications of activated charcoal in the manufacture of toothpastes and oral rinses: A narrative review. *J. Intl Oral. Health* **2023**, *15*, 237–241.
16. Ghajari, M.F.; Shamsaei, M.; Basandeh, K.; Galouyak, M.S. Abrasiveness and whitening effect of charcoal-containing whitening toothpastes in permanent teeth. *Dent. Res. J.* **2021**, *18*, 51. [CrossRef]
17. Maciel, C.R.O.; Amorim, A.A.; Oliveira, R.F.L.; Vivanco, R.G.; Pires-de-Souza, F.C.P. Whitening efficacy of popular natural products on dental enamel. *Braz. Dent. J.* **2022**, *33*, 55–66. [CrossRef]
18. Singh, R.P.; Sharma, S.; Logani, A.; Shah, N.; Singh, S. Comparative evaluation of tooth substance loss and its correlation with the abrasivity and chemical composition of different dentifrices. *Indian J. Dent. Res.* **2016**, *27*, 630–636.
19. Oshagh, M.; Khajeh, F.; Heidari, S.; Torkan, S. The effect of different environmental factors on force degradation of three common systems of orthodontic space closure. *Dent. Res. J.* **2015**, *12*, 50–56.
20. Baratieri, C.; Mattos, C.; Alves, M.J.; Lau, T.; Najomi, L.; Souza, M. In situ evaluation of orthodontic elastomeric chains. *Braz. Dent. J.* **2012**, *23*, 394–398. [CrossRef]
21. Mattos, F. *Avaliação Da Deformação de Cadeias Elásticas Submetidas a Diferentes Meios de Descontaminação São Paulo (SP)*; Universidade São Paulo: São Paulo, Brazil, 2013.
22. Araujo, F.; Ursi, W. Estudo da degradação da força gerada por elásticos ortodônticos sintéticos. *Rev. Dental Press. Ortod. Ortop. Facl.* **2006**, *11*, 52–61. [CrossRef]
23. Rock, W.P.; Wilson, H.J.; Fisher, S.E. A laboratory investigation of orthodontic elastomeric chains. *Br. J. Orthod.* **1985**, *12*, 202–207. [CrossRef] [PubMed]
24. Halimi, A.; Benyahia, H.; Doukkali, A.; Azeroual, M. A systematic review of force decay in orthodontic elastomeric power chains. *Int. Orthod.* **2012**, *10*, 223–240. [CrossRef]
25. Eliades, T.; Eliades, G.; Silikas, N.; Watts, D. Tensile properties of orthodontic elastomeric chains. *EJO* **2004**, *26*, 157–162. [CrossRef] [PubMed]
26. Aldrees, A.; Al-Foraidi, S.; Murayshed, M. Color stability and force decay of clear orthodontic elastomeric chains: An in vitro study. *Int. Orthod.* **2015**, *13*, 287–301. [CrossRef] [PubMed]