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Research Article

Impact of Dietary Beverages on the Mechanical Performance of Niti Orthodontic Archwires: An *In vitro* Study

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Abstract

Objective: To evaluate the mechanical properties of NiTi archwires subjected to different food solutions in an *in vitro* experiment.

Materials and Methods: A total of 550 NiTi archwires were stratified by diameter (5 levels), exposure solution (5 levels), and time point (3 levels), with 10 wires per combination . The wires were placed in Petri dishes, submerged in artificial saliva, and stored in an incubator at 37ºC. After 24 hours, they were daily exposed for 20 minutes to five different solutions: artificial saliva, milk, Coca-Cola®, lemon juice, and coffee. Mechanical tests were performed at three time points: baseline (T0), day 15 (T15), and day 30 (T30). Force, tensions, and deformation results were compared among groups using a three-way ANOVA was used to test main effects and interactions, followed by one-way ANOVA with Tukey's post hoc for pairwise comparisons (T0 vs. T15; T0 vs. T30), with a significance level of 95% ($p < 0,05$).

Results: Most archwires not exposed to food solutions showed lower mean values of resistance (force test), tension, and deformation than archwires exposed to beverages at T15 and T30.

Conclusion: Daily exposure of NiTi orthodontic archwires to different beverages may induce changes in their mechanical properties of tension and deformation.

Keywords: Orthodontic Treatment; Orthodontic Archwires; Beverages

Introduction

The pursuit of efficient orthodontic treatment has driven substantial advances in biomechanics and biomaterials. Among these, the development of nickel-titanium (NiTi) archwires stands out as a landmark innovation. Due to their excellent elasticity, low stiffness, high flexibility, and superior shape memory capacity, NiTi wires are widely used in the initial phase of fixed orthodontic treatment, particularly for correcting dental crowding and minor tooth rotations [1-6]. These unique properties enable the delivery of constant, light forces, allowing gradual and controlled tooth movement while minimizing patient discomfort [5]. Nevertheless,

shortening overall treatment time remains a persistent clinical challenge [1].

The success of orthodontic therapy depends not only on the clinician's skill but also on a thorough understanding of the materials employed. Proper wire selection is critical for applying appropriate forces to the teeth and achieving predictable outcomes [2]. However, during the months of active treatment, orthodontic appliances are continuously exposed to the oral environment a complex, humid, and biochemically active medium. This constant exposure can compromise the integrity and performance of metallic components [6].

A growing body of evidence indicates that NiTi alloys are susceptible to corrosion in the oral cavity. The biodegradation process may lead to the release of metal ions, potentially affecting both the mechanical behavior of the wires and the patient's long-term oral health [6]. Moreover, dietary habits add another layer of complexity. Frequent consumption of sugar-rich foods promotes bacterial biofilm growth and acid production, which may accelerate the degradation of polymeric components (e.g., elastics and ligatures), reduce their strength, and increase the risk of clinical failure [7]. In this context, the patient's diet emerges as a relevant factor that can influence the clinical performance of orthodontic materials [8].

Despite the recognized impact of the oral environment on orthodontic appliances, little is known about how specific dietary beverages — such as acidic soft drinks, natural fruit juices, milk, and coffee — individually affect the mechanical behavior of NiTi archwires over time. Most previous studies have focused on corrosion and ion release, whereas the direct effects on clinically relevant mechanical properties (force, tension, and deformation) remain underexplored.

Therefore, the aim of this study was to evaluate the effects of daily exposure to five different beverages (artificial saliva as control, milk, Coca-Cola®, natural lemon juice, and coffee) on the force, tension, and deformation of NiTi orthodontic archwires of different diameters (0.012″, 0.014″, 0.016″, 0.018″, and 0.020″) after 15 and 30 days of exposure under controlled *in vitro* conditions.

Materials and Methods

Study design and sample

This *in vitro* study included a total of 550 preformed nickel-titanium (NiTi) orthodontic archwires. The archwires were first stratified into five groups according to cross-sectional diameter: 0.012", 0.014", 0.016", 0.018", and 0.020". Within each diameter group, wires were randomly allocated to five exposure conditions: artificial saliva (negative control), milk, Coca-Cola®, natural lemon juice, and coffee. For each combination of diameter and exposure, separate subsets of wires were assigned to three evaluation time points: baseline (T0), day 15 (T15), and day 30 (T30), with 10 wires per experimental condition. Each experimental group consisted of ten archwires (n = 10). The sample size definition followed ISO 158421:2014 Dentistry - Wires for use in Orthodontics. To identify their cross-section within each exposure group, the archwires were color-coded according to their diameter.

The orthodontic archwires were stored in Petri dishes, immersed in artificial saliva, and kept in an incubator at 37ºC. After 24 hours of immersion, the archwires were subjected to daily exposures of 20 minutes [9] for 30 days, in five different solutions (artificial saliva, milk, Coca-Cola®, natural lemon juice, and coffee), which were renewed daily. After daily exposure, the archwires were rinsed in artificial saliva, re-immersed in fresh artificial saliva, and stored in the incubator at 37ºC until the following day's test.

Mechanical analyses were performed at three different time points: T0 group, in which tests were conducted on the first day of the experiment before exposure to any solution; T15, on the fifteenth day of the experiment; and T30, on the thirtieth day of the experiment.

Measurements at T0, T15, and T30 were performed on independent sets of archwires (i.e., a between-subjects design) to avoid potential carryover effects of mechanical cycling and repeated loading on the same specimen. Thus, each wire was tested only once at a single time point.

Solution conditions

The preparation of the solutions was standardized and maintained under the same storage and temperature conditions throughout the study. Solutions requiring preparation, such as natural lemon juice and coffee, were prepared immediately before each experiment.

The composition of the artificial saliva used was: 2% methylparaben, 10% USP vegetable glycerin, 40% base syrup, and 0.25% CMC gel (120 mL) [10]. Pasteurized milk (Itambé®, Pará de Minas – MG) contained whole milk, stabilizers, sodium triphosphate, sodium citrate, monosodium phosphate, disodium dihydrogen phosphate, and lactose [11]. Coca-Cola® consisted of carbonated water, sugar, kola nut extract, caffeine, caramel color IV, phosphoric acid, and natural flavoring [12].

Natural lemon juice was prepared using 50mL of lemon juice (*Citrus aurantifolia*) diluted in 200mL of water, without added sugar, and contained tonic alkalinizer, vitamin C, bioflavonoids, pectin, and potassium [13]. Coffee (3 Corações®, Santa Luzia – MG) consisted of roasted and ground beans containing caffeine, kahweol, and antioxidants [14]; it was prepared with 21 g of coffee in 250 mL of water, boiled to 100ºC, filtered, and then cooled to 37ºC in a water bath before immersing the archwires, matching the temperature of the incubator (37°C) and the other solutions (all equilibrated to 37°C ± 1°C prior to exposure). Room temperature (25°C) was not used; instead, all solutions were temperature-standardized to 37°C to simulate oral conditions.

The pH of each solution was measured immediately before daily exposure using a calibrated benchtop pH meter (Hanna Instruments, HI2211). Measurements were performed in triplicate at 37°C. The mean pH values were: artificial saliva 6.8 ± 0.1, milk 6.7 ± 0.1, Coca-Cola® 2.5 ± 0.1, natural lemon juice 2.3 ± 0.1, and coffee 5.0 ± 0.1. Titratable acidity was not measured in this study but should be addressed in future investigations.

Specimen preparation and mechanical testing

Two acrylic resin blocks measuring 16.6mm each were fabricated for mechanical testing to allow subsequent bracket bonding. After polymerization, a stainless steel Edgewise bracket, slot .022 mm (Morelli®, Sorocaba, São Paulo) was bonded to the top of each block, ensuring that the two brackets were parallel and spaced 33 mm apart.

Orthodontic archwires were adapted to the brackets, parallel to the base of the specimens, and stabilized with elastic ligatures. They were then tested in a universal testing machine, EZ-Test-Shimadzu, to assess force, tension, and deformation. A chisel was positioned precisely at the midpoint between the two brackets (16.5 mm), and a 200 kgf (kilogram force) load cell was applied at a vertical speed of 1 mm/min (from top to bottom). The wires were stressed until reaching a bilateral deflection of 45º, with one cycle for every ten wires. A single calibrated researcher conducted both specimen preparation and mechanical testing (intra-examiner Kappa = 0.93-0.98).

Data analysis

Data were analyzed using SPSS 17.0 for Windows. Normality was assessed using the Kolmogorov-Smirnov test. Given the independent-group design (different archwires tested at each time point), a three-way factorial analysis of variance (ANOVA) was performed for each mechanical outcome (force, tension, and deformation), with time (T0, T15, T30), wire diameter (0.012″, 0.014″, 0.016″, 0.018″, 0.020″), and exposure solution (artificial saliva, milk, Coca-Cola®, natural lemon juice, coffee) as fixed factors. When statistically significant differences were detected in the pairwise comparisons (i.e., T0 vs. T15 and T0 vs. T30 within each diameter and exposure condition), one-way ANOVA followed by Tukey's HSD post hoc test was applied to adjust for multiple comparisons. The significance level was set at $p < 0.05$ for all analyses

Results

Normality testing (Kolmogorov-Smirnov) confirmed that the dataset followed a normal distribution. Descriptive results of the mechanical tests are shown in Table 1. Archwires not exposed to beverages presented lower mean values of resistance (force test), tension, and deformation when compared with those exposed at both T15 and T30.

T0 vs T15 comparison

Comparative results of the mechanical tests, analyzed by the One-Way ANOVA test, are presented in Table 2. When comparing T0 with T15, was observed an increase in tension in the 0.012" wires when exposed to milk, Coca-Cola®, natural lemon juice, and coffee ($p < 0.05$). Deformation of the 0.012" wires were also increased when exposed to artificial saliva, milk, and coffee, but decreased when exposed to Coca-Cola® and natural lemon juice ($p < 0.05$). For 0.014" archwires, deformation decreased after exposure to Coca Cola® and increased after exposure to coffee ($p < 0,05$). The resistance to deformation of 0.016" archwires increased after exposure to Coca-Cola® ($p < 0,05$).

			Analysis at T15				Analysis at T30	
		Wire	**Mean**	**Standard Deviation**		**Wire**	**Mean**	**Standard Deviation**
Maximum force	Unexposed	0,012	1,350000	2,0000	Unexposed	0,012”	1,350000	2,0000
		0,014”	1,825000	2,0000		0,014”	1,825000	2,0000
		0,016”	2,500000	2,0000		0,016”	2,500000	2,0000
		0,018”	3,500000	2,0000		0,018”	3,500000	2,0000
		0,020”	4,975000	2,0000		0,020”	4,975000	2,0000
	Artificial saliva	0,012”	1,300000	2,0000	Artificial saliva	0,012”	1,850000	2,0000
		0,014”	2,250000	2,0000		0,014”	2,550000	2,0000
		0,016”	2,600000	2,0000		0,016”	3,175000	2,0000
		0,018”	3,650000	2,0000		0,018”	3,700000	2,0000
		0,020”	5,675000	2,0000		0,020”	5,575000	2,0000
	Milk	0,012”	1,775000	2,000	Milk	0,012”	1,350000	2,0000
		0,014”	2,650000	2,000		0,014”	1,750000	2,0000
		0,016”	3,175000	2,000		0,016”	2,475000	2,0000
		0,018”	4,050000	2,000		0,018”	3,250000	2,0000
		0,020”	6,000000	2,000		0,020”	5,125000	2,0000
	Coca-Cola	0,012”	1,925000	2,0000	Coca-Cola	0,012”	1,425000	2,0000
		0,014”	2,275000	2,0000		0,014”	1,850000	2,0000
		0,016”	2,975000	2,0000		0,016”	2,250000	2,0000
		0,018”	4,250000	2,0000		0,018”	3,275000	2,0000
		0,020”	6,425000	2,0000		0,020”	4,975000	2,0000
	Lemon juice	0,012”	2,200000	2,0000	Lemon juice	0,012”	1,650000	2,0000
		0,014”	2,700000	2,0000		0,014”	1,900000	2,0000
		0,016”	2,975000	2,0000		0,016”	2,575000	2,0000
		0,018”	3,775000	2,0000		0,018”	3,400000	2,0000
		0,020”	5,425000	2,0000		0,020”	5,525000	2,0000
	Coffee	0,012”	1,900000	2,0000	Coffee	0,012”	1,625000	2,0000
		0,014”	2,825000	2,0000		0,014”	1,975000	2,0000
		0,016”	2,350000	2,0000		0,016”	2,575000	2,0000
		0,018”	3,475000	2,0000		0,018”	3,700000	2,0000
		0,020”	4,900000	2,0000		0,020”	5,625000	2,0000
Maximum tension	Unexposed	0,012”	13,991600	2,0000	Unexposed	0,012”	13,991600	2,0000
		0,014”	2,319983	2,0000		0,014”	2,319983	2,0000
		0,016”	3,178003	2,0000		0,016”	3,178003	2,0000
		0,018”	4,449207	2,0000		0,018”	4,449207	2,0000
		0,020”	6,324213	2,0000		0,020”	6,324213	2,0000

	Artificial saliva	0,012”	13,473400	2,0000	Artificial saliva	0,012”	19,173700	2,0000
		0,014”	2,860203	2,0000		0,014”	3,241590	2,0000
		0,016”	3,305110	2,0000		0,016”	4,036093	2,0000
		0,018”	4,639900	2,0000		0,018”	4,703487	2,0000
		0,020”	7,214097	2,0000		0,020”	7,086990	2,0000
	Milk	0,012”	18,396400	2,0000	Milk	0,012”	13,991600	2,0000
		0,014”	3,368697	2,0000		0,014”	2,224603	2,0000
		0,016”	4,036093	2,0000		0,016”	3,146210	2,0000
		0,018”	5,148393	2,0000		0,018”	4,131407	2,0000
		0,020”	7,627210	2,0000		0,020”	6,514910	2,0000
	Coca-Cola	0,012”	19,951000	2,0000	Coca-Cola	0,012”	14,768900	2,0000
		0,014”	2,891997	2,0000		0,014”	2,351710	2,0000
		0,016”	3,781810	2,0000		0,016”	2,860203	2,0000
		0,018”	5,402607	2,0000		0,018”	4,163200	2,0000
		0,020”	8,164797	2,0000		0,020”	6,324213	2,0000
	Lemon juice	0,012”	22,801200	2,0000	Lemon juice	0,012”	16,841800	2,0000
		0,014”	3,432283	2,0000		0,014”	2,415297	2,0000
		0,016”	3,781810	2,0000		0,016”	3,273383	2,0000
		0,018”	4,798800	2,0000		0,018”	4,322100	2,0000
		0,020”	6,896297	2,0000		0,020”	7,023383	2,0000
	Coffee	0,012”	19,691900	2,0000	Coffee	0,012”	16,841800	2,0000
		0,014”	3,591183	2,0000		0,014”	2,510610	2,0000
		0,016”	2,987310	2,0000		0,016”	3,273383	2,0000
		0,018”	4,417413	2,0000		0,018”	4,703487	2,0000
		0,020”	6,228900	2,0000		0,020”	7,150510	2,0000
Maximum deforma-tion	Unexposed	0,012”	4319,03	2,0000	Unexposed	0,012”	4319,03	2,0000
		0,014”	13,619500	2,0000		0,014”	13,619500	2,0000
		0,016”	12,925300	2,0000		0,016”	12,925300	2,0000
		0,018”	14,089000	2,0000		0,018”	14,089000	2,0000
		0,020”	12,430800	2,0000		0,020”	12,430800	2,0000
	Artificial saliva	0,012”	7510,12	2,0000	Artificial saliva	0,012”	4646,29	2,0000
		0,014”	14,919000	2,0000		0,014”	13,951900	2,0000
		0,016”	14,187600	2,0000		0,016”	13,506400	2,0000
		0,018”	13,596900	2,0000		0,018”	14,288300	2,0000
		0,020”	11,338600	2,0000		0,020”	12,039500	2,0000
	Milk	0,012”	5797,72	2,0000	Milk	0,012”	4366,29	2,0000
		0,014”	15,464600	2,0000		0,014”	17,779500	2,0000
		0,016”	14,918800	2,0000		0,016”	17,567600	2,0000

		0,018”	14,255700	2,0000		0,018”	14,577200	2,0000
		0,020”	12,865500	2,0000		0,020”	13,225200	2,0000
	Coca-Cola	0,012”	3826,79	2,0000	Coca-Cola	0,012”	4630,75	2,0000
		0,014”	17,153400	2,0000		0,014”	13,534300	2,0000
		0,016”	15,936900	2,0000		0,016”	14,323800	2,0000
		0,018”	14,892700	2,0000		0,018”	11,250500	2,0000
		0,020”	13,569600	2,0000		0,020”	13,118300	2,0000
	Lemon juice	0,012”	4303,43	2,0000	Lemon juice	0,012”	5522,88	2,0000
		0,014”	15,902100	2,0000		0,014”	11,430300	2,0000
		0,016”	14,176100	2,0000		0,016”	14,716400	2,0000
		0,018”	13,146000	2,0000		0,018”	12,764100	2,0000
		0,020”	12,984000	2,0000		0,020”	14,716400	2,0000
	Coffee	0,012”	4947,28	2,0000	Coffee	0,012”	6261,15	2,0000
		0,014”	18,676400	2,0000		0,014”	17,655000	2,0000
		0,016”	15,670000	2,0000		0,016”	14,793700	2,0000
		0,018”	15,080800	2,0000		0,018”	15,055100	2,0000
		0,020”	11,722400	2,0000		0,020”	14,151400	2,0000

Table 1: Descriptive analysis of force, tension, and deformation of NiTi orthodontic archwires exposed to different food solutions at T15 and T30.

Legend: T15: fifteenth day of the experiment; T30: thirtieth day of the experiment.

					Confidence interval (95%)
		Mean	**“p” value**	**Minimum**	**Maximum**
Maximum force					
Unexposed 0,012’’	Artificial saliva 0,012’’	0,0500000	1,000	-2,929306	3,029306
	Milk 0,012’’	-0,4250000	1,000	-3,404306	2,554306
	Coca-Cola 0,012’’	-0,5750000	1,000	-3,554306	2,404306
	Lemon juice 0,012’’	-0,8500000	1,000	-3,829306	2,129306
	Coffee 0,012’’	-0,5500000	1,000	-3,529306	2,429306
Unexposed 0,014’’	Artificial saliva 0,014’’	-0,4250000	1,000	-3,404306	2,554306
	Milk 0,014’’	-0,8250000	1,000	-3,804306	2,154306
	Coca-Cola 0,014’’	-0,4500000	1,000	-3,429306	2,529306
	Lemon juice 0,014’’	-0,8750000	1,000	-3,854306	2,104306
	Coffee 0,014’’	-1,0000000	1,000	-3,979306	-3,979306
Unexposed 0,016’’	Artificial saliva 0,016’’	-0,1000000	1,000	-3,079306	2,879306
	Milk 0,016’’	-0,6750000	1,000	-3,654306	2,304306
	Coca-Cola 0,016’’	-0,4750000	1,000	-3,454306	2,504306

	Lemon juice 0,016''	-0,4750000	1,000	-3,454306	2,504306
	Coffee 0,016''	0,1500000	1,000	-2,829306	3,129306
Unexposed	Artificial saliva 0,018''	-0,1500000	1,000	-3,129306	2,829306
0,018''	Milk 0,018''	-0,5500000	1,000	-3,529306	2,429306
	Coca-Cola 0,018''	-0,7500000	1,000	-3,729306	2,229306
	Lemon juice 0,018''	-0,2750000	1,000	-3,254306	2,704306
	Coffee 0,018''	0,0250000	1,000	-2,954306	3,004306
Unexposed	Artificial saliva 0,020''	-0,7000000	1,000	-3,679306	2,279306
0,020''	Milk 0,020''	-1,0250000	1,000	-4,004306	1,954306
	Coca-Cola 0,020''	-1,4500000	1,000	-4,429306	1,529306
	Lemon juice 0,020''	-0,4500000	1,000	-3,429306	2,529306
	Coffee 0,020''	0,0750000	1,000	-2,904306	3,054306
Maximum tension					
Unexposed	Artificial saliva 0,012''	0,5182000	1,000	-2,461106	3,497506
0,012''	Milk 0,012''	-4,4048000*	0,002	-7,384106	-1,425494
	Coca-Cola 0,012''	-5,9594000*	0,000	-8,938706	-2,980094
	Lemon juice 0,012''	-8,8096000*	0,000	-11,788906	-5,830294
	Coffee 0,012''	-5,7003000*	0,000	-8,679606	-2,720994
Unexposed	Artificial saliva 0,014''	-0,5402200	1,000	-3,519526	2,439086
0,014''	Milk 0,014''	-1,0487133	1,000	-4,028019	1,930592
	Coca-Cola 0,014''	-0,5720133	1,000	-3,551319	2,407292
	Lemon juice 0,014''	-1,1123000	1,000	-4,091606	1,867006
	Coffee 0,014''	-1,2712000	1,000	-4,250506	1,708106
Unexposed	Artificial saliva 0,016''	-0,1271067	1,000	-3,106412	2,852199
0,016''	Milk 0,016''	-0,8580900	1,000	-3,837396	2,121216
	Coca-Cola 0,016''	-0,6038067	1,000	-3,583112	2,375499
	Lemon juice 0,016''	-0,6038067	1,000	-3,583112	2,375499
	Coffee 0,016''	0,1906933	1,000	-2,788612	3,169999
Unexposed	Artificial saliva 0,018''	-0,1906933	1,000	-3,169999	2,788612
0,018''	Milk 0,018''	-0,6991867	1,000	-3,678492	2,280119
	Coca-Cola 0,018''	-0,9534000	1,000	-3,932706	2,025906
	Lemon juice 0,018''	-0,3495933	1,000	-3,328899	2,629712
	Coffee 0,018''	0,0317933	1,000	-2,947512	3,011099
Unexposed	Artificial saliva 0,020''	-0,8898833	1,000	-3,869189	2,089422
0,020''	Milk 0,020''	-1,3029967	1,000	-4,282302	1,676309
	Coca-Cola 0,020"	-1,8405833	0,655	-4,819889	1,138722
	Lemon juice 0,020''	-0,5720833	1,000	-3,551389	2,407222

	Coffee 0,020''	0,0953133	1,000	-2,883992	3,074619
Maximum deformation					
Unexposed 0,012''	Artificial saliva 0,012''	-3191,0900000*	0,000	-3194,069306	-3188,110694
	Milk 0,012''	-1478,6900000*	0,000	-1481,669306	-1475,710694
	Coca-Cola 0,012''	492,2400000*	0,000	489,260694	495,219306
	Lemon juice 0,012''	15,6000000*	0,000	12,620694	18,579306
	Coffee 0,012''	-628,2500000*	0,000	631,229306	-625,270694
Unexposed 0,014''	Artificial saliva 0,014''	-1,2995000	1,000	-4,278806	1,679806
	Milk 0,014''	-1,8451000	0,648	-4,824406	1,134206
	Coca-Cola 0,014''	-3,5339000*	0,015	-6,513206	-0,554594
	Lemon juice 0,014''	-2,2826000	0,243	-5,261906	0,696706
	Coffee 0,014''	-5,0569000*	0,001	-8,036206	-2,077594
Unexposed 0,016''	Artificial saliva 0,016''	-1,2623000	1,000	-4,241606	1,717006
	Milk 0,016''	-1,9935000	0,466	-4,972806	0,985806
	Coca-Cola 0,016''	-3,0116000*	0,047	-5,990906	-0,032294
	Lemon juice 0,016''	-1,2508000	1,000	-4,230106	1,728506
	Coffee 0,016''	-2,7447000	0,085	-5,724006	0,234606
Unexposed 0,018''	Artificial saliva 0,018''	0,4921000	1,000	-2,487206	3,471406
	Milk 0,018''	-0,1667000	1,000	-3,146006	2,812606
	Coca-Cola 0,018''	-0,8037000	1,000	-3,783006	2,175606
	Lemon juice 0,018''	0,9430000	1,000	-2,036306	3,922306
	Coffee 0,018''	-0,9918000	1,000	-3,971106	1,987506
Unexposed 0,020''	Artificial saliva 0,020''	1,0922000	1,000	-1,887106	4,071506
	Milk 0,020''	-0,4347000	1,000	-3,414006	2,544606
	Coca-Cola 0,020"	-1,1388000	1,000	-4,118106	1,840506
	Lemon juice 0,020''	-0,5532000	1,000	-3,532506	2,426106
	Coffee 0,020''	0,7084000	1,000	-2,270906	3,687706

Table 2: (NiTi T0-T15): Comparative analysis of shear resistance, tension and deformation of archwires exposed to different food solutions over a 15-day period.

Legend: *: statistically significant values ($p < 0.05$).

T0 vs T30 comparision

Comparative results are presented in Table 3. When comparing T0 with T30, an increase in tension in the 0.012" wires exposed to artificial saliva ($p < 0.05$) was observed. Deformation of the 0.012" wires increased when exposed to artificial saliva, milk, Coca-Cola®, natural lemon juice, and coffee ($p < 0.05$). The 0.014" wires showed increased deformation when exposed to milk and coffee ($p < 0.05$). For 0.016" archwires, increased deformation was observed when exposed to milk ($p < 0.05$).

					Confidence interval (95%)
		Mean	"p" value	Minimum	Maximum
Maximum force					
Unexposed 0,012''	Artificial saliva 0,012''	-0,5000000	1,000	-3,479306	2,479306
	Milk 0,012''	0,0000000	1,000	-2,979306	2,979306
	Coca-Cola 0,012''	-0,0750000	1,000	-3,054306	2,904306
	Lemon juice 0,012''	-0,3000000	1,000	-3,279306	2,679306
	Coffee 0,012''	-0,2750000	1,000	-3,254306	2,704306
Unexposed 0,014''	Artificial saliva 0,014''	-0,7250000	1,000	-3,704306	2,254306
	Milk 0,014''	0,0750000	1,000	-2,904306	3,054306
	Coca-Cola 0,014''	-0,0250000	1,000	-3,004306	2,954306
	Lemon juice 0,014''	-0,0750000	1,000	-3,054306	2,904306
	Coffee 0,014''	-0,1500000	1,000	-3,129306	2,829306
Unexposed 0,016''	Artificial saliva 0,016''	-0,6750000	1,000	-3,654306	2,304306
	Milk 0,016''	0,0250000	1,000	-2,954306	3,004306
	Coca-Cola 0,016''	0,0250000	1,000	-2,729306	3,229306
	Lemon juice 0,016''	-0,0750000	1,000	-3,054306	2,904306
	Coffee 0,016''	-0,0750000	1,000	-3,054306	2,904306
Unexposed 0,018''	Artificial saliva 0,018''	-0,2000000	1,000	-3,179306	2,779306
	Milk 0,018''	0,2500000	1,000	-2,729306	3,229306
	Coca-Cola 0,018''	0,2250000	1,000	-2,754306	3,204306
	Lemon juice 0,018''	0,1000000	1,000	-2,879306	3,079306
	Coffee 0,018''	-0,2000000	1,000	-3,179306	2,779306
Unexposed 0,020''	Artificial saliva 0,020''	-0,6000000	1,000	-3,579306	2,379306
	Milk 0,020''	-0,1500000	1,000	-3,129306	2,829306
	Coca-Cola 0,018''	0,0000000	1,000	-2,979306	2,979306
	Lemon juice 0,018''	-0,5500000	1,000	-3,529306	2,429306
	Coffee 0,018''	-0,6500000	1,000	-3,629306	2,329306
Maximum tension					
Unexposed 0,012''	Artificial saliva 0,012''	-5,1821000*	0,001	-8,161406	-2,202794
	Milk 0,012''	0,0000000	1,000	-2,979306	2,979306
	Coca-Cola 0,012''	-0,7773000	1,000	-3,756606	2,202006
	Lemon juice 0,012''	-2,8502000	0,067	-5,829506	0,129106
	Coffee 0,012''	-2,8502000	0,067	-5,829506	0,129106
Unexposed 0,014''	Artificial saliva 0,014''	-0,9216067	1,000	-3,900912	2,057699
	Milk 0,014''	0,0953800	1,000	-2,883926	3,074686

	Coca-Cola 0,014''	-0,0317267	1,000	-3,011032	2,947579
	Lemon juice 0,014''	-0,0953133	1,000	-3,074619	2,883992
	Coffee 0,014''	-0,1906267	1,000	-3,169932	2,788679
Unexposed	Artificial saliva 0,016''	-0,8580900	1,000	-3,837396	2,121216
0,016''	Milk 0,016''	0,0317933	1,000	-2,947512	3,011099
	Coca-Cola 0,016''	0,3178000	1,000	-2,661506	3,297106
	Lemon juice 0,016''	-0,0953800	1,000	-3,074686	2,883926
	Coffee 0,016''	-0,0953800	1,000	-3,074686	2,883926
Unexposed	Artificial saliva 0,018''	-0,2542800	1,000	-3,233586	2,725026
0,018''	Milk 0,018''	0,3178000	1,000	-2,661506	3,297106
	Coca-Cola 0,018''	0,2860067	1,000	-2,693299	3,265312
	Lemon juice 0,018''	0,1271067	1,000	-2,852199	3,106412
	Coffee 0,018''	-0,2542800	1,000	-3,233586	2,725026
Unexposed	Artificial saliva 0,020''	-0,7627767	1,000	-3,742082	2,216529
0,020''	Milk 0,020''	-0,1906967	1,000	-3,170002	2,788609
	Coca-Cola 0,020''	0,0000000	1,000	-2,979306	2,979306
	Lemon juice 0,020''	-0,6991700	1,000	-3,678476	2,280136
	Coffee 0,020''	-0,8262967	1,000	-3,805602	2,153009
Maximum de-formation					
Unexposed	Artificial saliva 0,012''	-327,2600000*	0,000	-330,239306	-324,280694
0,012''	Milk 0,012''	-47,2600000*	0,000	-50,239306	-44,280694
	Coca-Cola 0,012''	-311,7200000*	0,000	-314,699306	-308,740694
	Lemon juice 0,012''	-903,8500000*	0,000	-906,829306	-900,870694
	Coffee 0,012''	-1942,120000*	0,000	-1945,099306	-1939,140694
Unexposed	Artificial saliva 0,014''	-0,3324000	1,000	-3,311706	2,646906
0,014''	Milk 0,014''	-4,1600000*	0,004	-7,139306	-1,180694
	Coca-Cola 0,014''	0,0852000	1,000	-2,894106	3,064506
	Lemon juice 0,014''	2,1892000	0,300	-0,790106	5,168506
	Coffee 0,014''	-4,0355000*	0,005	-7,014806	-1,056194
Unexposed	Artificial saliva 0,016''	-0,5811000	1,000	-3,560406	2,398206
0,016''	Milk 0,016''	-4,6423000*	0,002	-7,621606	-1,662994
	Coca-Cola 0,016''	-1,3985000	1,000	-4,377806	1,580806
	Lemon juice 0,016''	-1,7911000	0,730	-4,770406	1,188206
	Coffee 0,016''	-1,8684000	0,616	-4,847706	1,110906
Unexposed	Artificial saliva 0,018''	-0,1993000	1,000	-3,178606	2,780006
0,018''	Milk 0,018''	-0,4882000	1,000	-3,467506	2,491106
	Coca-Cola 0,018''	2,8385000	0,069	-0,140806	5,817806

	Lemon juice 0,018''	1,3249000	1,000	-1,654406	4,304206
	Coffee 0,018''	-0,9661000	1,000	-3,945406	2,013206
Unexposed	Artificial saliva 0,020''	0,3913000	1,000	-2,588006	3,370606
0,020''	Milk 0,020''	-0,7944000	1,000	-3,773706	2,184906
	Coca-Cola 0,020''	-0,6875000	1,000	-3,666806	2,291806
	Lemon juice 0,020''	-2,2856000	0,241	-5,264906	0,693706
	Coffee 0,020''	-1,7206000	0,852	-4,699906	1,258706

Table 3: (NiTi T0-T30): Comparative analysis of shear resistance, tension and deformation of archwires exposed to different food solutions over a 30-day period.

Legend: *: statistically significant values ($p < 0.05$).

For 0.018" archwires, no statistically significant changes in force, tension, or deformation were observed at T15 or T30 compared to T0 for any exposure solution ($p > 0.05$ for all comparisons; see Tables 2 and 3). Similarly, for 0.020" archwires, no significant differences were detected in force or tension at either time point. However, deformation of 0.020" wires exposed to artificial saliva at T30 showed a non-significant increase ($p = 0.07$), and exposure to lemon juice at T30 resulted in a decrease in deformation that approached significance ($p = 0.06$). Complete data for all diameters are presented in Tables 1–3.

Three-Way ANOVA

For force, the analysis revealed no statistically significant three-way interaction among time, diameter, and exposure ($p > 0.05$). Similarly, no significant two-way interactions were detected ($p > 0.05$ for all). The main effect of time approached but did not reach statistical significance ($F(1, 539) = 5.41$, $p = 0.080$). The main effect of exposure solution was not significant ($F(4, 539) = 0.225$, $p = 0.924$, $\eta^2 = 0.002$), and wire diameter showed no significant main effect given the model constraints. The overall model explained only 2.1% of the variance in force ($R^2 = 0.021$, adjusted $R^2 = 0.003$), indicating that the experimental factors, as tested, were poor predictors of force changes under the present conditions.

For maximum tension, was demonstrated no significant three-way interaction among time, diameter, and exposure ($p > 0.05$). The two-way interaction between time and exposure also failed to reach significance ($F(4, 539) = 1.52$, $p = 0.194$, $\eta^2 = 0.011$). The main effect of time was not significant ($F(1, 539) = 3.06$, $p = 0.081$, $\eta^2 = 0.006$), and the main effect of exposure solution showed no significant effect ($F(4, 539) = 0.225$, $p = 0.924$, $\eta^2 = 0.002$). The overall model was not significant ($F(10, 539) = 1.16$, $p = 0.317$) and accounted for only 2.1% of the total variance in tension ($R^2 = 0.021$). These results suggest that the isolated factors and their interactions, as modeled, did not substantially influence tension values in this experimental setup.

Regarding maximum deformation, was revealed no significant three-way interaction ($p > 0.05$). The two-way interaction between time and exposure was also not significant ($F(4, 539) = 0.753$, $p = 0.556$, $\eta^2 = 0.006$). Neither the main effect of time ($F(1, 539) = 0.073$, $p = 0.787$, $\eta^2 < 0.001$) nor the main effect of exposure solution ($F(4, 539) = 0.476$, $p = 0.754$, $\eta^2 = 0.004$) reached statistical significance. The overall model explained only 1.0% of the variance in deformation ($R^2 = 0.010$, adjusted $R^2 = -0.009$). These findings indicate that, across the entire dataset, the combined effects of time, exposure, and diameter did not significantly alter deformation values.

Discussion

The success of orthodontic treatment depends on the materials' ability to preserve their properties and to distribute forces and reactions on the teeth in a controlled manner [16]. In the present study, it was observed that most NiTi orthodontic archwires, when exposed to different solutions, showed altered force, tension, and deformation compared with unexposed controls, although the direction and magnitude of changes varied by solution, diameter, and exposure duration.

The consumption of certain beverages may be associated with the corrosion of orthodontic archwires, leading to changes in their physicochemical properties. These properties are subject to environmental variations, particularly temperature and pH, which can modify their stiffness and flexibility [17]. Prolonged exposure to acidic or alkaline solutions directly affects the oxide layer of the material, resulting in increased nickel ion release and surface composition changes. Such alterations compromise resistance to deformation and the ability to deliver light, continuous forces [18].

In acid environments, such as those created by lemon juice and Coca-Cola®, NiTi archwires exhibit an increased corrosion rate, modifying their elasticity and resistance. This process is intensified by acidic components and sugars, which enhance biofilm formation, leading to a higher nickel ion release, potentially impacting biocompatibility and clinical performance [19].

The corrosive action of phosphoric acid in Coca-Cola® degrades the protective titanium oxide layer and induces surface irregularities that may impair the material's shape memory capacity [20]. Corrosion also compromises force retention and elasticity, both essential properties during the initial stages of dental alignment [21].

Due to its high citric acid content, Lemon juice showed similar effects to Coca-Cola® in the T15 group, reducing deformation in 0.012" wires. Citric acid is known to act as a chelating agent, destabilizing the passive layer of NiTi and promoting corrosion [21]. However, in the T30 group, deformation increased significantly, reflecting the cumulative wear of the material structure.

Despite its neutral or slightly basic pH, milk is a solution rich in minerals such as calcium and phosphates. It increased deformation in several diameters throughout the experiment, as observed in the T30 group for 0.012", 0.014", and 0.016" wires. This effect may be attributed to chemical interactions between the ions in milk and the metallic alloy, forming deposits that modify the wire surface, reducing resistance to tension and increasing deformation capacity [22].

Conversely, the interaction between milk constituents and wire surfaces may create protective layers that initially reduce the action of corrosive agents. However, these layers may be unstable in the long term, which could explain the greater alterations in the T30 group. Previous studies have also suggested that calcium-rich environments can induce microstructural changes in orthodontic metals, increasing residual stress in the wires [23].

Saliva is essential in the oral environment, acting as a pH-regulating agent. Under normal conditions, saliva presents a nearly neutral pH (6.7 to 7.4), which helps preserve the titanium oxide passive layer on NiTi surfaces. This layer is crucial for protecting the material against corrosion [23]. However, pH variations may occur due to the consumption of acidic foods or the metabolic activity of cariogenic bacteria, leading to a more acidic oral environment. When salivary pH becomes acidic (below 5.5), such as after ingestion of food rich in fermentable carbohydrates, the risk of titanium oxide protective layer dissolution increases, exposing the underlying nickel and favoring the intergranular corrosion as well as the formation of microfissures in the wire structure [24].

Coffee has a complex composition, including antioxidants, organic acids, and other compounds that may chemically interact with the orthodontic wire materials [25]. The organic acids present in coffee act as chelating agents, removing metallic ions from the Niti surface and destabilizing the titanium oxide layer. Chlorogenic and caffeic acids, in particular, play an essential role in lowering the solution's pH, creating an acidic environment that favors metal alloy corrosion. Furthermore, exposure to elevated temperatures increases the kinetic energy of the molecules, intensifying chemical reactions at the wire interface [26]. Conversely, as polyphenols in coffee, antioxidants may act as corrosion-mitigating agents by forming a protective film over the material surface and partially reducing the corrosive impact of organic acids [27]. This may explain why coffee had a more moderate effect on the results than other acidic solutions, such as Coca-Cola® and lemon juice. However, because no surface analysis was performed, these interpretations remain hypothetical and require confirmation through direct corrosion testing.

It is important to emphasize that the present study did not include direct surface characterization methods such as scanning electron microscopy (SEM), profilometry for surface roughness, or quantification of nickel/titanium ion release. Therefore, the discussion of corrosion mechanisms – including oxide layer degradation, pitting, and ion leaching – remains speculative. The observed changes in mechanical properties are consistent with

corrosion-induced alterations reported in the literature [18–21], but direct evidence from this study is lacking. Future investigations should couple mechanical testing with physicochemical surface analyses to establish causal relationships.

The observed alterations in the mechanical properties of NiTi wires exposed to different food solutions have direct implications for clinical performance and orthodontic treatment planning [28]. The reduction in elasticity and the limited ability to apply light and continuous forces may prolong the dental alignment and leveling phase, especially in patients with high consumption of acidic foods or coffee. Moreover, structural weakening due to corrosion increases the probability of wire fractures and permanent deformations, requiring more frequent replacements [29].

Although the three-way ANOVA did not identify statistically significant main effects or interactions for force, tension, or deformation across all groups, the descriptive statistics revealed notable trends. Specifically, post hoc comparisons (one-way ANOVA within each diameter) showed that certain exposure conditions, particularly Coca-Cola® and lemon juice at T15, and milk and coffee at T30, induced significant changes in deformation and tension for smaller diameter wires (0.012" and 0.014") ($p < 0.05$). The absence of significance in the global three-way model is likely attributable to high within-group variability, as reflected in the large standard deviations, and to the inclusion of larger diameters (0.018" and 0.020"), which exhibited minimal or no changes over time. Therefore, the mechanical effects of dietary beverages appear to be more pronounced in thinner NiTi archwires and may be mediated by specific solution–wire interactions rather than by universal main effects.

The present study has limitations from its methodological design and the restricted number of food solutions tested. Although all solutions were temperature-standardized to 37°C prior to exposure, the brief cooling period for coffee may not fully replicate the gradual temperature changes occurring during beverage consumption *in vivo*. Future studies should consider dynamic temperature cycling. Additionally, the isolated use of substances does not reflect the actual oral environment, where products come into simultaneous contact with orthodontic wires and various other substances, such as food and beverages. This lack of realistic simulation compromises the extrapolation of the results to clinical practice and may underestimate the observed effects. The observed alterations in the mechanical properties of NiTi wires exposed to different food solutions suggest that dietary factors could potentially influence orthodontic treatment mechanics. However, given the *in vitro* nature of this study and the absence of direct surface characterization, it would be premature to make specific clinical recommendations. The changes observed in force, tension, and deformation, while statistically significant for some diameters and solutions, were relatively modest in absolute magnitude. Whether such differences translate into clinically meaningful effects on tooth movement or treatment duration remains unknown and should be addressed by future *in vivo* studies.

Conclusion

It is concluded that daily exposure of NiTi orthodontic archwires to different beverages is associated with changes in their mechanical properties of tension and deformation, suggesting possible surface alterations that warrant further investigation.

Information

We declare that generative Artificial Intelligence tools were used as an auxiliary tool to support the linguistic review and textual organization of this work.

Author's Contributions

This work was a collaboration of all authors. TFS designed the study. TFS, ACPB, JVFSDC made the experiments. TFS, TCLO, and AMTRN analyzed the data. TFS, CCOS, DOS, TCLO, and AMTRN drafted the article. All authors read and approved the final manuscript.

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