Effect Of Fluoride Treatment On The Mechanical Properties Of Orthodontic Archwires - An In Vitro Study

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ABSTRACT

INTRODUCTION: Orthodontic treatment success relies on well-designed wires that balance strength, flexibility, and range of motion. Maintaining oral hygiene is crucial during treatment to prevent enamel demineralization and decay, exacerbated by plaque buildup around brackets. Fluoride supplements are often recommended to mitigate these risks but can potentially corrode orthodontic wires, leading to reduced mechanical performance and wire fractures.
AIM & OBJECTIVES: The purpose of this study was to evaluate the effects of fluoride treatment on the mechanical properties of four different orthodontic arch wires, namely Nickel-Titanium (NiTi), Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium (CuNiTi) and Coaxial Stainless-Steel after exposure to a predetermined time.
MATERIAL AND METHODOLOGY: 120 archwires—Nickel-Titanium (NiTi), Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium (CuNiTi), and 6-Stranded Coaxial Stainless-Steel—were tested. Pre-adjusted edgewise brackets were bonded to artificial teeth, and wires were ligated using elastomeric ties. Archwire samples were immersed in fluoride mouthwash and incubated, then tested for Modulus of Elasticity, Yield Strength, and Deflection using a Universal Testing Machine.
RESULTS: All wire types showed significant reductions in mechanical properties after fluoride exposure, with NiTi wires experiencing the most pronounced decline, and 6-Stranded Coaxial Stainless-Steel wires demonstrating the least change.
CONCLUSION: Topical fluoride significantly diminishes the mechanical strength of orthodontic archwires due to corrosion, compromising their effectiveness during initial treatment phases and potentially extending treatment times.

KEYWORDS: White spot lesions, Orthodontic archwires, Fluoride, mechanical properties

INTRODUCTION

Orthodontic intervention plays a pivotal role in enhancing and sustaining optimal oral and dental health, fostering a visually pleasing smile that contributes significantly to the cultivation of self-esteem.[3] White Spot Lesions (WSLs) around orthodontic appliances pose challenges due to plaque accumulation and acid production.[9] Fluoride prophylactic agents help prevent these lesions but can affect the mechanical properties of archwires, potentially increasing friction and surface roughness. It reacts with bacterial products, leading to the production of Hydrofluoric Acid, which causes the dissolution of the surface's protective oxide layer and results in corrosion of both brackets and wires.[21]
Maintaining optimal oral hygiene is crucial during orthodontic treatment to prevent complications such as corrosion and alteration in the properties of wire.[23] Different types of archwires, including Stainless-Steel, Nickel-Titanium, and Copper-Nickel-Titanium, are used sequentially to align teeth effectively.
The wires utilized for initial alignment must possess excellent strength, springiness, and a wide range of action. Familiarity with their mechanical properties greatly aids clinicians in devising and implementing optimal force systems during orthodontic treatment. Understanding the mechanical behavior of these archwires is crucial for achieving effective tooth movement and favorable treatment outcomes.[14]
The primary goal of this study was to examine how exposure to a commonly used fluoride prophylactic agent for a set period affects the mechanical properties (including Modulus of Elasticity, Yield Strength, and Deflection at 1 percentage strain) of different types of orthodontic archwires.
Given the advantageous role of prophylactic agents in preventing decalcification around orthodontic brackets, this study aimed to investigate whether

exposure to fluoride prophylactic agents leads to alterations in the mechanical properties of archwires.

AIM OF STUDY

•The purpose of this study was to evaluate the effects of fluoride treatment on the mechanical properties of different archwires used in the orthodontic therapy.

OBJECTIVES OF STUDY

•To compare the mechanical properties i.e., Modulus of elasticity, Yield strength and Deflection at 1 percentage Strain of four different orthodontic arch wires, namely Nickel-Titanium (NiTi), Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium (CuNiTi) and Coaxial Stainless-Steel after exposure to commonly used fluoride prophylactic agents for a predefined period of time.

METHODOLOGY

This study was conducted at the Department of Orthodontics & Dentofacial Orthopedics, Dasmesh Institute of Research & Dental Sciences, Faridkot. It aimed to assess the Modulus of Elasticity, Yield Strength, and Deflectio0n of four types of Orthodontic Archwires (Nickel-Titanium, Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium, and 6-Stranded Coaxial Stainless-Steel) after exposure to a fluoride prophylactic agent (Figure 1).

FIGURE 1:Showing four types of Orthodontic wires (A) G&H 0.016" Niti Archwire; (B) Speed Supercable 0.016" Coaxial Superelastic NiTiArchwire; (C) G&H 0.016" Cu Ni Ti Archwire; (D) G&H 0.0155" 6 stranded Coaxial S.S. Archwire

Thirty samples each of four types of Orthodontic archwires commonly used in initial leveling and alignment were collected. The selected wires were grouped under four groups:
Each group was further subdivided into two sub-groups depending upon the solution they were emersed in(Table 1):
•Sub-Group A : Control group •Sub-GroupB:Experimental group
The Sub-Groups were tabulated as follows:

Archwire	Sub-Groups	Type of Solution	No. of Wires
0.016″ NiTi	Group I A	Artificial saliva	15
	Group I B	Fluoride solution	15
0.016″ Coaxial SuperelasticNiTi	Group II A	Artificial saliva	15
	Group II B	Fluoride solution	15
0.016″ CuNiTi	Group III A	Artificial saliva	15
	Group III B	Fluoride solution	15
0.0155″ S.S. Coaxial	Group IV A	Artificial saliva	15
	Group IV B	Fluoride solution	15

TABLE 1: Representing division of wires among different groups according to their composition (Group I-IV) (Figure 1)

Standard pre-adjusted edgewise brackets (0.022" slot, MBT prescription) and all- single molar tubes were used and bonded on artificial teeth mounted on an API typhodont set. Elastomeric ligatures secured the wires to brackets (Figure 2).

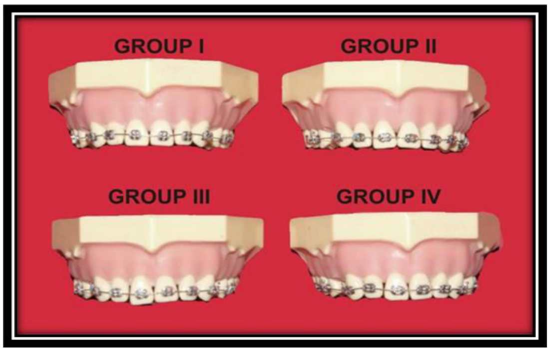


FIGURE 2: API Typhodont set with four different types of orthodontic archwires ligated to the brackets using grey elastic module

The archwires were placed in a glass container and immersed in acidulated phosphate fluoride mouthwash and artificial saliva for 90 minutes at 37°C to simulate clinical conditions (Figure 3). This duration of 90 minutes was equivalent to three months of daily rinsing with fluoride mouthwash for one minute (Walker et al., American Journal of Orthodontics and Dentofacial Orthopedics Volume 127, Number 6, 2015).

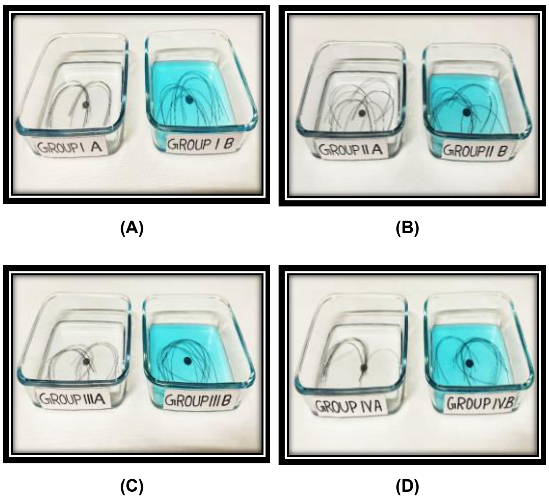


FIGURE 3: Four types of Orthodontic wires immersed in a container containing artificial saliva on right side and Fluoride solution on left side (A) G&H 0.016" Niti Archwire; (B) Speed Supercable 0.016" Coaxial SuperelasticNiTiArchwire; (C) G&H 0.016" CuNiTiArchwire; (D) G&H 0.0155" Coaxial S.S. Archwire

Before testing, the specimens were removed from their respective solutions and were rinsed with distilled water. A laboratory testing system was designed to reproduce as closely as possible the situation in the mouth. The setup included a phantom head jaw fixture with a plastic tooth secured by a screw at the root apex so that individual teeth could be removed easily. The typodont was mounted to the UTM with the help of screws so that the testing segment i.e. wire segment between teeth #14 and #15, #24 and #25, #34 and #35, #44 and #45 was directly beneath the rod attached to the UTM. This rod applied force to the wire segment, which was tested for Modulus of Elasticity, Yield Strength, and Deflection using four different Orthodontic archwires (Figure 4).

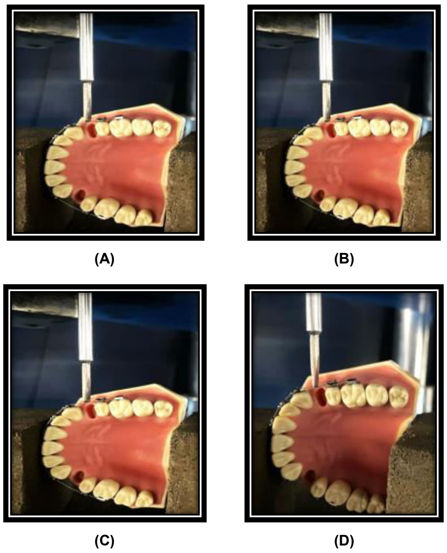


FIGURE 4: Depicting wires at (A) G&H 0.016" Niti Archwire; (B) Speed Supercable 0.016" Coaxial SuperelasticNiTiArchwire; (C) G&H 0.016" CuNiTiArchwire; (D) G&H 0.0155" Coaxial S.S. Archwire under Bend test in the Universal Testing Machine for the measurement of Yield Strength, Modulus of Elasticity and Deflection at 1% Strain.

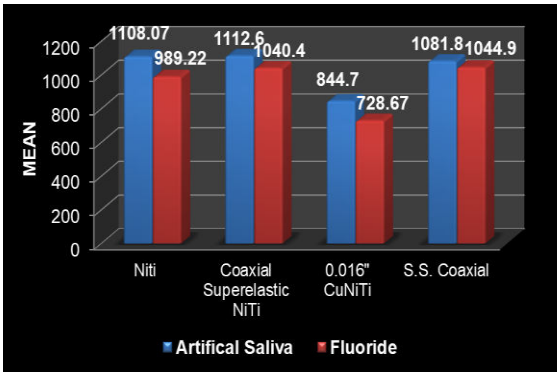
A cross-head speed of 1mm/min was consistently used during the study. Statistical analyses, including Student's t-test, ANOVA, and Post Hoc Tukey's test ($\alpha = 0.05$), were conducted to assess the effect of fluoride treatment on the wires.

RESULTS

Based on the results of the study evaluating the effects of fluoride treatment on different types of orthodontic archwires, the Student t-test evaluated the Yield Strength, Modulus of Elasticity and Deflection at 1% Strain of the four archwire samples and compared the two sub-groups; control and experimental.
The mean and standard deviation of all the readings of Groups 1, 2, 3 & 4 and their Sub-Groups were calculated. The comparison of mean values of the four groups are depicted in Graph No. 1, 2 & 3.
The results showed that:

Yield Strength:

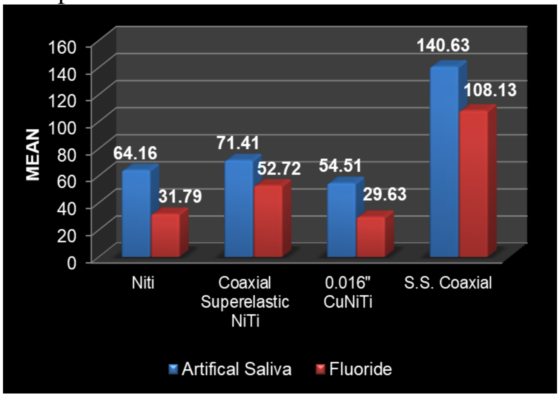
- There was a statistically significant difference between the control and experimental group
- Archwires (NiTi, Coaxial SuperelasticNiTi&CuNiTi) showed significant reduction in yield strength after fluoride treatment ($p \leq 0.001$) with 0.016 inch NiTiarchwire showing the maximum reduction in Yield strength after Fluoride treatment .
- 6-stranded Coaxial SS wire did not exhibit a significant reduction in yield strength after fluoride treatment ($p \leq 0.001$). See Graph No. 1 for comparisons.



GRAPH 1: Comparison of mean Yield strength values in different groups of Orthodontic Archwires

Modulus of Elasticity:

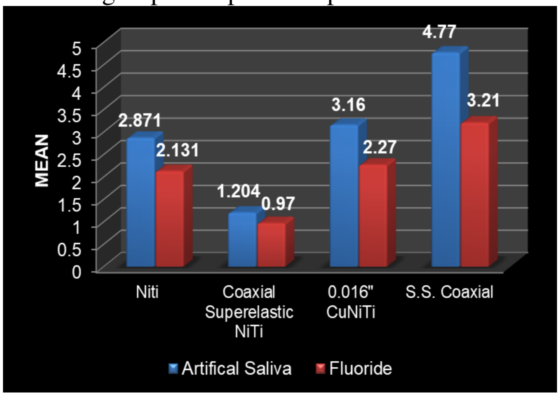
- Significant differences were found in the modulus of elasticity between control and experimental groups.
- All wire types (NiTi, Coaxial SuperelasticNiTi, CuNiTi& 6-stranded Coaxial SS) demonstrated significant decreases in modulus of elasticity after fluoride treatment ($p \leq 0.001$) with 0.016 inchNiTi group showing the maximum change. Graph No. 2 illustrates these differences.



GRAPH 2: Comparison of mean Modulus of Elasticity values in different groups of Orthodontic Archwires

Deflection at 1% Strain:

- Significant differences were detected in deflection at 1% strain between control and experimental groups when compared with Student t-test.
- Fluoride treatment led to significant reductions in wire deflection for all types (NiTi, Coaxial SuperelasticNiTi, 0.016" CuNiTi, 6-stranded Coaxial SS) ($p \leq 0.001$).
- The 0.0155 inch Coaxial SS archwire showed the most change when treated with fluoride when the deflection was compared in all the four groups. Graph No. 3 provides a visual comparison.



GRAPH 3: Comparison of mean Deflection at 1% Strain in different groups of Orthodontic Archwires

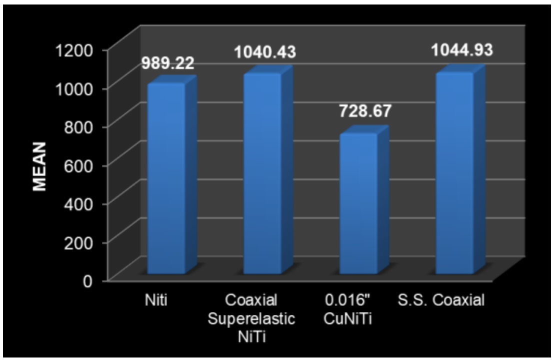
Hence, each comparison demonstrated statistically significant differences between the control (artificial saliva) and experimental (fluoride) groups across all measured properties (Yield Strength, Modulus of Elasticity, and Deflection at 1% Strain).

INTER-GROUP COMPARISON OF FOUR DIFFERENT TYPE OF WIRES AFTER FLUORIDE TREATMENT

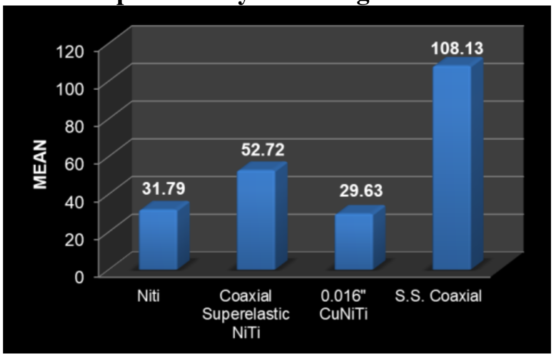
When evaluating the mechanical properties (Yield Strength, Modulus of Elasticity, and Deflection) between the experimental groups of the four types of archwires, comparisons were made.

The overall mean values of four major groups were calculated & compared. Tukey's HSD test was done to do comparison among these groups i.e. Nickel-Titanium, Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium and 6-Stranded Coaxial Stainless-Steel (Graph 4,5 & 6).

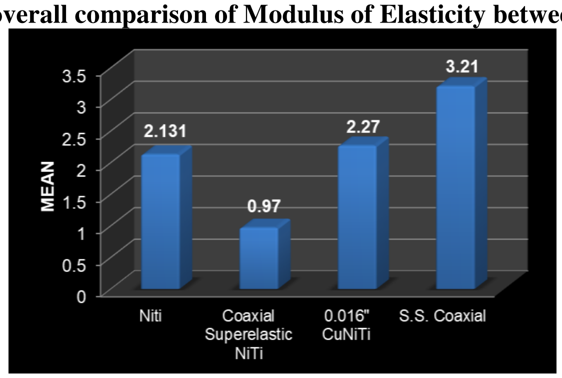
It was observed that 6-Stranded Coaxial Stainless-Steel archwire when treated with fluoride solution and observed under the Universal Testing Machine had better mechanical properties, i.e. Yield Strength, Modulus of Elasticity and Deflection at 1% Strain as compared to other initial levelling and alignment archwires used in this study. When compared with other Titanium alloy archwires, the Coaxial SS wire showed the least change when immersed in fluoride solution compared to their control group.



GRAPH 4: Depicting overall comparison of yield strength between the four groups of wires.



GRAPH 5: Depicting overall comparison of Modulus of Elasticity between the four groups of wires



GRAPH 6: Depicting overall comparison of Deflection at 1% strain between the four groups of wires

DISCUSSION

The research aimed to analyze how exposure to fluoride affects the mechanical properties of orthodontic archwires. These properties are important in the first phase of fixed appliance orthodontic treatment, which involves leveling and aligning the teeth. During alignment, the goal is to position the edges of the anterior teeth and the cusps of the posterior teeth horizontally, while leveling aims to achieve a normal contact point relationship across the dental arch.[5]

Orthodontic theories emphasize the use of light and continuous forces for controlled tooth movement, requiring wires that are flexible yet capable of transmitting sufficient forces. This initial phase is critical as it sets the foundation for subsequent treatment stages.[5]

Two principal types of wires are recommended based on the elastic property, ratios of strength, stiffness and range of action - multi-stranded Stainless-Steel and Nitinol-type wires.[16]

Stainless-Steel wires, specifically the multi-stranded type, are known for their low stiffness, resilience, and cost-effectiveness, though they exhibit higher friction at bracket interfaces compared to NiTi wires[19]whereas theNickel-Titanium wires, known for their shape memory and superelastic properties, having revolutionized the orthodontic treatment by enabling lighter forces and shorter treatment times.[7] Copper Nickel-Titanium (CuNiTi) wires, a variant with added copper, offer reduced loading stress and consistent force generation, particularly beneficial in orthodontic tooth movement**.**[2]To simulate oral conditions, Type III CuNiTi was chosen for testing as these wires have a Transition Temperature Range (TTR) of 37°C, which is close to oral temperature.

The study highlighted the detrimental effects of fluoride exposure on these wires. Fluoride from mouthwashes and dental products can lead to corrosion by disrupting the protective oxide layer on NiTi and SS wires. This corrosion significantly reduces the mechanical properties such as Yield Strength and Modulus of Elasticity, affecting the efficacy and durability of orthodontic treatment.[10]

In the current study, the four most commonly used initial leveling and alignment archwires, namely Nickel-Titanium (NiTi), Coaxial Superelastic Nickel-Titanium, Copper-Nickel-Titanium (CuNiTi) and 6-Stranded Coaxial Stainless-Steel wire were used. These wires were exposed to artificial saliva and fluoride solution for 1.5hrs. This exposure time was equivalent to 3 months of 1-minute daily topical fluoride applications.[22] It is based on the recommended concentration of fluoride mouthwash advised to orthodontic patients on daily basis.[4]

A laboratory testing system was developed to replicate, as accurately as feasible, the conditions present in the oral cavity. This system utilized a phantom head model with a jaw structure where each plastic tooth was anchored by a screw at its root apex, facilitating easy removal of individual teeth. The teeth were arranged in proper alignment and exhibited good contact, with the exception of the first premolar, which was intentionally extracted.[18]

The advantage of this methodology was that the jig was specially designed to simulate the arch form and the mid-span distance, wherein the beveled chisel of the Universal Testing Machine strikes, was selected based on the standard inter-bracket distance.[16] The extraction span length was set to match the average span size during the first premolar extraction cases.

Universal Testing Machine evaluations demonstrated significant decreases in mechanical properties post-exposure, particularly in NiTi and CuNiTi wires, whereas the multi-stranded Stainless-Steel wires exhibited greater resistance to fluoride-induced corrosion.[4]

Ramalingam et al., Mane et al.and Kaur et al. conducted a study on the effects of fluoride on the Yield Strength and Modulus of Elasticity of NiTi and Cu-NiTiarchwires.[15,12,8] Their findings showed that when exposed to fluoride, the mechanical properties of the archwires decreased significantly. These results are consistent with the outcomes obtained from our own study.

Coaxial Superelastic Nickel-Titanium archwire showed better mechanical properties than Nickel-Titanium and Copper Nickel-Titanium archwires. Since the wire was made of several Nickel-Titanium wires placed coaxially together, the yield strength of the wire was significantly increased, resulting in better overall strength.

Similarly, fluoride solution when exposed to Stainless-Steel dissolves the chromium oxide coating layer and therefore, the corrosion resistance of the archwire decreases significantly along with a decrease in its mechanical properties.[13]

The results showed a significant change in Yield Strength, Modulus of Elasticity and Deflection at 1% Strain for the coaxial S.S. archwire after immersion in a fluoride solution when compared to the control group.

These results are consistent with those evaluated by Hammad et al.and Aghil et al., who also studied the effects of fluoride on NiTi and multistranded SS wires. The results indicate that fluoride has an adverse impact on the mechanical properties of both NiTi and SS wires.[6,1]

Ramalingam et al., Sabane, Mane et al. and Kaur et al. conducted a study on the effects of fluoride on the Yield Strength and Modulus of Elasticity of NiTi and CuNiTi archwires.[15,20,12,8] Their findings showed that when exposed to fluoride, the mechanical properties of the archwires decreased significantly. These results are consistent with the outcomes obtained from our study.

According to Rerhrhaye et al.'s study, Stainless-Steel has a higher modulus of elasticity.[17] However, this value declines significantly in an acidic and fluoridated medium for NiTiarchwires. Our present study aligns with these findings, demonstrating that Stainless-Steel archwires are less affected by fluoride compared to titanium-based wires in terms of their mechanical properties.

Results similar to the current study have been reported before by Rucker et al. who performed the bending test to compare the elastic properties of single-stranded Niti and SS wires with Multistranded NiTi and SS archwires; however, to date, there are no previous studies investigating the effect of fluoride on the mechanical properties of multistranded NiTi wire.[19]

The study's findings underscored the importance of material selection in orthodontics, particularly in environments with frequent fluoride exposure. The 6-stranded Coaxial Stainless-Steel archwire emerged as relatively resistant to fluoride, making it suitable in cases where oral hygiene may be compromised pre-treatment.

Limitations included the in-vitro nature of the study, which did not fully replicate the complexities of the oral environment. Variables such as diet, salivary pH, and bacterial activity, which could influence fluoride's impact on wires clinically, were not fully accounted for. Future research should explore cumulative effects of repeated, shorter fluoride exposures on orthodontic wires to better inform clinical practice.

In conclusion, while fluoride remains essential for dental health, its corrosive effects on orthodontic wires necessitate careful consideration in treatment planning and material selection to mitigate potential impacts on treatment outcomes and patient care.

CONCLUSION

This in-vitro study assessed the mechanical properties (Yield Strength, Modulus of Elasticity, Deflection at 1% strain) of popular orthodontic archwires used for initial leveling and alignment. The study yielded the following conclusions:

1.Following immersion in fluoride mouthwash, there was a significant decrease in the yield strength of all four types of wires. Nickel-Titanium archwires experienced the most substantial reduction, while 6-stranded Coaxial Stainless Steel wires showed the least change.
2.The modulus of elasticity significantly decreased in all 0.016" wire samples after fluoride immersion. The Coaxial SuperelasticNiTiarchwire demonstrated the least notable alteration, whereas the NiTi group showed the most significant change.
3.When comparing the deflection at 1% strain among the four 0.016" wire samples, the CuNiTi group showed the most substantial change, whereas the Coaxial SuperelasticNiTiarchwire exhibited the least change.
4.Upon intergroup comparison, it was concluded that the 6-stranded Coaxial Stainless-Steel archwire, after fluoride treatment, demonstrated superior mechanical properties when compared to the other wire groups because of lack of effect of fluoride on the mechanical properties of multi-stranded Stainless-Steel wire because of the composition of wire whereby chromium and nickel impart corrosion resistance. Therefore, the wire showed the least change.
The study concludes that daily use of fluoride mouthwashes, aimed at preventing white spot lesions, can significantly compromise the mechanical integrity of orthodontic archwires during initial treatment stages. Continuous fluoride exposure in the oral cavity accelerates wire corrosion, potentially prolonging treatment times.

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