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Coating stability of different esthetic NiTi archwires under high fluoride exposure

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Abstract

Objective: This in-vitro study evaluated the coating stability of various esthetic archwires exposed to high fluoride levels.

Methods: Ninety 0.016-inch esthetic nickel-titanium (NiTi) archwires were divided into three groups based on the type of coating (n=30): Group 1, rhodium-coated; Group 2, Teflon-coated; and Group 3, epoxy-coated. Each group was divided into three subgroups and kept in the following medium (n=10): A, artificial saliva with three ppm fluoride; B, plain artificial saliva; and C, as-received condition. In subgroups, A and B, 20 mm segments from NiTi archwires were immersed in test tubes containing the corresponding medium for 28 days. Afterwards, mechanical stress was applied to the samples *of three groups* using an electric toothbrush. The surface topography of the archwires in all subgroups was then examined by a stereomicroscope. Areas of coating loss were quantified using Capture 2.3 software. Statistical analysis was performed using two-way ANOVA, with a significance level of $P<0.05$.

Results: ANOVA revealed no significant difference in coating loss among the study groups in the as-received condition ($P=1.000$) and after exposure to plain artificial saliva ($P=0.651$); however, in fluoride-containing artificial saliva, a significant difference was observed ($P<0.01$). Epoxy-coated wires had significantly greater coating loss than rhodium- and Teflon-coated wires ($P<0.001$). All groups showed a significantly higher coating loss in fluoride-containing artificial saliva than both plain artificial saliva and as-received subgroups ($P<0.05$).

Conclusions: Epoxy-coated archwires exhibited the highest degradation in fluoride-containing artificial saliva, whereas Teflon- and rhodium-coated NiTi archwires showed better coating stability after fluoride exposure.

Keywords: Epoxy resins, Fluoride, Nitinol, Orthodontic wires, Polytetrafluoroethylene, Rhodium

Introduction

The demand for improved esthetics in orthodontic treatment has led to the development of appliances that balance adequate clinical performance with acceptable esthetics (1-3). Advancements in material science have resulted in the introduction of novel esthetic archwires. The first transparent, nonmetallic esthetic orthodontic wire, Optiflex, featured a silica core, a silicone resin middle layer, and a stain-resistant nylon outer layer (4, 5). Thereafter, Fallis and Kusy introduced an esthetic wire made of S2 glass fibers embedded in a polymeric matrix (6). Later, fiber-reinforced polymer archwires were introduced, offering improved esthetics over earlier archwires. However, despite their superior appearance, the brittle nature of polymer archwires limited their clinical use (7). To overcome this deficit, manufacturers developed various coatings for metallic archwires (8, 9).

The materials commonly used for coating archwires include Teflon, epoxy, and rhodium. Teflon is a brand name for polytetrafluoroethylene (PTEF) polymer, which is well-known for its non-stick and heat-resistant features. The Teflon coating is applied using clean compressed air, followed by heat treatment in a chamber furnace (8, 10). Epoxy-coated archwires are manufactured through electrostatic coating, where a high-voltage charge is applied to the archwire, followed by air-spraying of liquid epoxy particles (11, 12). Rhodium-coated archwires are manufactured through ion implantation, with strong adhesion between the wire and the coating (13). These coated archwires not only enhance esthetics but also might reduce friction and surface roughness, compared to non-coated archwires (14, 15).

Although esthetic archwires are designed to provide an improved appearance, several studies have reported

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challenges associated with their clinical performance (16-19). Increased friction between archwires and brackets, color changes over time, and coating detachment have been observed during the intraoral use of esthetic archwires (9, 16-18). Research indicates that after clinical exposure, partial peeling of the coating occurs in multiple areas, increasing surface roughness (9, 19). These changes can be identified using stereomicroscopy, and coating loss can be quantified using software such as AutoCAD or Image ProPlus. Despite these drawbacks, esthetic archwires are still used when superior esthetics are prioritized (19).

Various experimental studies have assessed the impact of fluoride-containing prophylactic agents and staining solutions on the mechanical properties and color stability of esthetic archwires (20, 21). Additionally, intraoral factors such as salivary pH, enzymatic activity, chewing forces, and tooth brushing can affect the surface roughness, strength, and friction properties of these archwires (22, 23).

Despite the increasing use of esthetic archwires, limited data exist on their coating stability in high-fluoride environments. The effect of fluoride exposure is important in high-risk caries patients undergoing fluoride treatments, as well as those living in fluorosis-endemic regions with elevated fluoride levels. This study aimed to evaluate the effects of fluoride exposure on the coating stability of various esthetic NiTi archwires, to understand their durability under such conditions.

Materials and methods

This in-vitro study was conducted at the Department of Orthodontics and Dentofacial Orthopedics at Sri Rajiv Gandhi College of Dental Sciences and Hospital, Bangalore, India. In total, ninety 0.016-inch NiTi esthetic archwires with three different coatings were selected:

Group 1 (n=30), rhodium-coated (Energie archwires, Ortho One Inc., India).

Group 2 (n=30) Teflon-coated (Hygi Pak System, Orthodent, India).

Group 3 (n=30) epoxy-coated (Rabbit Force, Libral Traders Pvt. Ltd., India).

Each group of archwires was further divided into three subgroups (n=10) based on the immersion medium:

Subgroup A: Artificial saliva containing three ppm fluoride.

Subgroup B: Plain artificial saliva.

Subgroup C: As-received coated archwires without any exposure to artificial saliva.

The sample size was determined using power analysis with a significance level of 0.05 and power of 80%, according to a previous study (22).

The posterior parts of the archwires were sectioned into 20 mm segments, with an additional 2 mm for secure placement during mechanical stress testing. In subgroups A and B, wire specimens were placed into test tubes containing either fluoride-containing or plain artificial saliva for 28 days. The artificial saliva was carefully prepared according to the modified Fusayama-Meyer formula, which included 0.4 g/L sodium chloride, 0.4 g/L potassium chloride, 0.8 g/L calcium chloride, 0.69 g/L sodium hydrogen phosphate, 1 g/L urea, and 0.005 g/L sodium sulfide, with pH adjusted to 6.75. Sodium fluoride was added to saliva to achieve a final fluoride concentration of 3 ppm (3 mg/L), which was verified using an ion-selective electrode. This concentration was chosen to simulate the fluoride exposure found in regions with fluoridated drinking water (11,22).

After the 28-day exposure period, samples from subgroups A and B were dried and subjected to mechanical stress on the entire archwire surfaces, whereas subgroup C also underwent the same mechanical stress immediately after being obtained from the market. This stress was applied using a rotating electric toothbrush (Oral-B Vitality; Procter & Gamble, Cincinnati,

OH, USA), and each 20 mm wire segment was brushed for 420 seconds (Figure 1). This duration was based on the assumption of twice-daily toothbrushing over 28 days, as recommended by previous studies (22), and aligns with clinical findings showing that commercially available coated archwires can exhibit partial to complete coating loss within this timeframe of intraoral use (22). Following the mechanical stress, the surface topography of each wire was examined using a

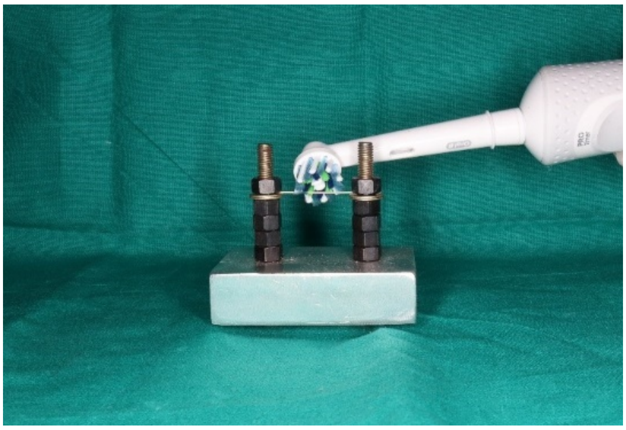

Figure 1. The experimental stand securing the wire and applying mechanical stress using an electric toothbrush

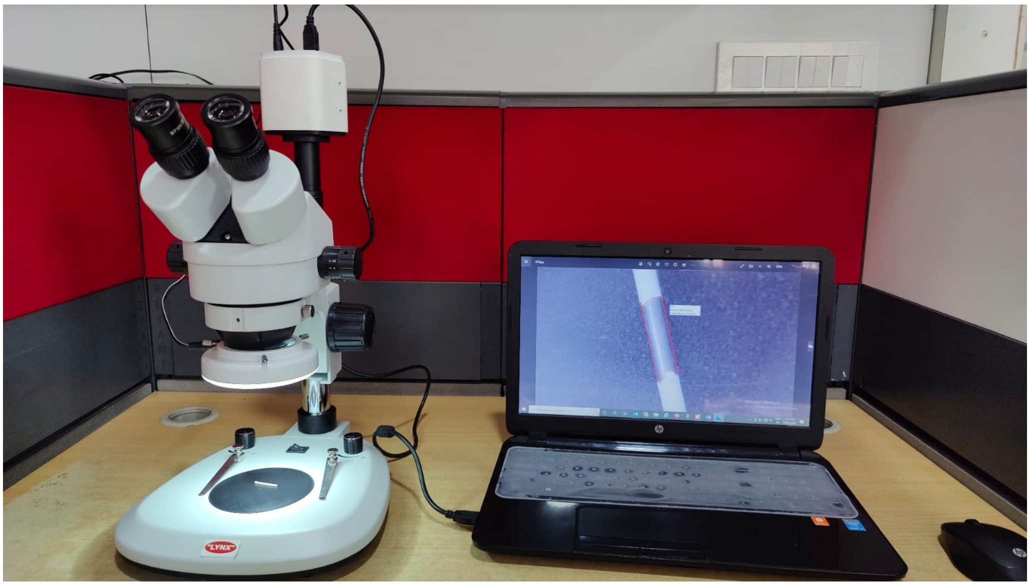

Figure 2. The stereomicroscope and Capture 2.3 software used for coating loss measurement

stereomicroscope (Lynx., India) at 35× magnification. Digital images of the surface were recorded for analysis.

To quantify the coating loss, the images were processed using Capture 2.3 software, which allowed for identifying and measuring the area where the coating had been lost (Figures 2 and 3). For each wire, three independent measurements of the coating loss were taken to ensure accuracy, and the mean coating loss was calculated.

Statistical Analysis

The data obtained from the coating loss measurements were analyzed using SPSS software (version 21; IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was applied to assess the normality of the data distribution ($P>0.05$). Two-way ANOVA was used to assess the effect of coating type and immersion medium on coating loss. A p-value of less than 0.05 was considered statistically significant.

Results

The results of two-way ANOVA revealed a significant interaction between the coating type and immersion medium ($P<0.05$). Therefore, the effect of each variable on coating loss of esthetic archwires was assessed by one-way ANOVA.

In fluoride-containing artificial saliva, epoxy-coated NiTi archwires exhibited the highest mean coating loss (0.506 ± 0.204 mm^2), followed by rhodium-coated (0.215 ± 0.048 mm^2) and Teflon-coated (0.201 ± 0.075 mm^2) NiTi archwires. One-way ANOVA revealed that the difference in coating loss among the three groups was statistically significant ($P<0.001$, Table 1). Further pairwise comparisons using the post-hoc Bonferroni test revealed that the mean coating loss in epoxy-coated NiTi wires was significantly higher than in both rhodium-coated ($P<0.001$) and Teflon-coated wires ($P<0.001$), whereas no significant difference was found between rhodium-coated and Teflon-coated wires ($P=1.000$).

In the plain artificial saliva subgroup, epoxy-coated NiTi wires again demonstrated the highest loss (0.082 ± 0.057 mm^2), followed by Teflon-coated (0.066 ± 0.056 mm^2) and rhodium-coated NiTi wires (0.060 ± 0.045 mm^2). One-way ANOVA showed no significant difference in coating loss among the three groups in plain artificial saliva ($P = 0.651$).

None of the coating materials exhibited coating loss in the as-received archwires without exposure to artificial saliva (0.000 ± 0.000 mm^2 for all groups).

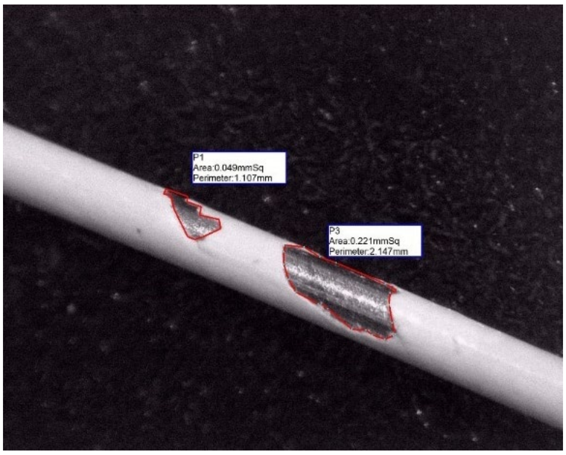

Figure 3. Measuring the area of coating loss on the archwire

Table 1. Mean and standard deviation of coating loss (mm^2) in different groups and subgroups

Groups	Subgroups			Intra-group P-value[b]
	Fluoride-containing artificial saliva	Plain artificial saliva	As-received archwires	
Rhodium-coated NiTi wires	0.215 ± 0.048 [a]	0.060 ± 0.045	0.000 ± 0.000	< 0.001*
Teflon-coated NiTi wires	0.201 ± 0.075 [a]	0.066 ± 0.056	0.000 ± 0.000	< 0.001*
Epoxy-coated NiTi wire>	0.506 ± 0.204 [b]	0.082 ± 0.057	0.000 ± 0.000	< 0.001*
Inter-group P-value [a]	< 0.001*	0.651	1.000	

An asterisk (*) indicated a significant difference at P<0.05.
Different superscript lowercase letters indicate statistical difference among groups at P<0.05.

Intra-group comparisons using an independent samples t-test demonstrated significantly higher coating loss in fluoride-containing artificial saliva compared to plain artificial saliva in all study groups (P < 0.001 for all).

Discussion

The growing demand for esthetic orthodontic appliances has led to the development of modern esthetic archwires, including coated metallic archwires (24). The materials commonly used for coating include Teflon, epoxy, and rhodium. This in-vitro study assessed the stability of three different esthetic-coated NiTi wires after exposure to high fluoride levels compared to non-fluoride conditions.

The present findings indicated that all three coated NiTi archwires experienced coating loss when exposed to artificial saliva containing high fluoride levels. However, the epoxy-coated archwire exhibited the most significant coating loss compared to the rhodium- and Teflon-coated groups. This finding aligns with the study by Jejurikar et al. (12), which reported maximum coating loss in epoxy archwires after 4 to 6 weeks, suggesting lower coating stability in this material. The observed coating loss in epoxy-coated wires may be attributed to the absorption of water by epoxy resin, which leads to cracking and subsequent delamination (25). Additionally, the manufacturing process and coating application method may have contributed to the differences in coating stability. Albuquerque et al. (26) concluded that the mechanical properties and surface morphology of esthetic archwires were significantly influenced by the coating process rather than the coating material itself.

Mechanical stimulation, such as toothbrushing, could have further contributed to the coating loss observed in this study. Abdulkader et al. (22) demonstrated that mechanical stress from an electric toothbrush accelerated the degradation of coating layers. Similarly, Ito et al. (25) recommended using softer brush filaments in patients with esthetic-coated archwires to minimize coating degradation.

Other factors may also influence the amount of coating degradation in the oral environment. Prior studies have evaluated the coating stability of esthetic archwires in the oral environment, attributing degradation to enzymatic activity and masticatory forces (12,19,27,28). Argalji et al. (27) reported that polymeric-coated wires maintained esthetics better than Teflon-coated NiTi archwires after 21 days of oral exposure. They also reported that coating loss began at the corners, where tensile stress accumulated, and the coating was thinner.

In this study, no coating loss was observed in the as-received archwires when examined under a stereomicroscope. However, Silva et al. (19) noted coating delamination, irregularities, and surface defects in the as-received coated wires under SEM, which may have resulted from manufacturing factors. When exposed to plain artificial saliva, all three coated NiTi archwires in the present study showed some coating loss, though the difference between groups was not statistically significant. In contrast, Abdulkader et al. (22) observed that PTFE-coated archwires exhibited significantly greater stability than epoxy-coated archwires in plain artificial saliva.

The outcomes of this study align with some studies that reported the detrimental impact of fluoride on the mechanical properties of esthetic-coated archwires. Aghili et al. (29) reported that, aside from surface morphology changes, esthetic-coated archwires exhibited reduced force levels compared to non-coated NiTi wires after exposure to fluoride-containing mouthwashes. Hammad et al. (30) found that fluoride therapy significantly decreased the modulus of elasticity in translucent composite wires.

The clinical relevance of this study is particularly important in patients with a high risk of caries who undergo fluoride therapy at maximum concentrations and also in patients living in fluorosis-endemic regions, where high fluoride exposure could accelerate coating degradation, compromising both the longevity and clinical performance of esthetic archwires. The present findings indicate that Teflon- and rhodium-coated NiTi wires offer superior coating stability compared to epoxy-coated wires, making them a more durable option for orthodontic patients undergoing fluoride therapy or living in fluoride-endemic regions.

A key strength of this study was assessing the entire archwire surface rather than only the labial side. A limitation of the study was the use of archwire segments rather than full-length archwires, which may not fully replicate clinical conditions. Additionally, variations in coating thickness between brands and within the same brand might influence coating stability. Future research should focus on improving coating techniques and exploring alternative materials to enhance coating durability. This study was conducted under in-vitro conditions, which cannot fully replicate the complex oral environment, including salivary composition, pH fluctuations, mastication forces, and biofilm presence. Therefore, further in-vivo studies are needed to understand better the long-term clinical impact of fluoride exposure on different properties of esthetic archwires.

Conclusions

This study demonstrated that esthetic-coated NiTi archwires exhibit varying degrees of coating degradation when exposed to artificial saliva with high fluoride levels. Among the tested coatings, Teflon and rhodium-coated archwires exhibited superior stability, while epoxy-coated archwires showed the most significant coating loss. Therefore, epoxy-coated archwires may be less suitable for clinical use in fluoride-rich environments.

Acknowledgements

There is nothing to declare.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

P.J. and R.N.G.R. contributed to the research design and implementation; K.R. contributed to the writing of the manuscript and data analysis; G.A. contributed to research supervision and analysis. All authors read and approved the final manuscript.

Ethical approval

This study was approved by the ethical committee of Rajiv Gandhi University of Health Sciences (No. SRGCDS/2020/154)

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