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Original Article

Changes in Color Stability and Surface Roughness of Teflon-Coated Arch Wires After Clinical Use

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Main Points

- Esthetic wires cannot maintain their surface integrity after clinical use.
- Coating materials should be strengthened.
- The core material of the esthetic arch wires can be enhanced to make antibacterial release.

ABSTRACT

Objective: Peeling of polytetrafluoroethylene (Teflon)-coated esthetic arch wires results in rough surfaces that may cause plaque accumulation, and the exposed core material may not meet the esthetic expectations of patients. The aim of this study was to evaluate the in-vivo surface roughness, *Streptococcus mutans* colonization, and color stability of Teflon-coated arch wires from 3 different manufacturers.

Methods: Surface roughness and color data of 0.016-inch and 0.016 × 0.022-inch Teflon-coated arch wires from 3 different manufacturers were recorded as they were received (T0) and after 28 days of clinical exposure (retrieved) (T1) using an atomic force microscope and a spectrophotometer. The amount of *S. mutans* was assessed in terms of colony-forming units on the as-received and retrieved wires.

Results: The surface roughness increased significantly, and a clinically noticeable color change was observed in all groups after clinical use ($P < .005$). There was no statistically significant difference in the amount of *S. mutans* adhesion for most of the wires. No significant correlation was found between the amount of *S. mutans* adhesion and the surface roughness.

Conclusion: All the arch wires showed increased surface roughness and clinically noticeable color change. The surface roughness values were not found to be correlated with the amount of *S. mutans* adhesion.

Keywords: Color change, esthetic orthodontic arch wire, surface roughness, Teflon-coated arch wire

INTRODUCTION

The lack of esthetic appearance of orthodontic appliances is one of the greatest concerns for orthodontic patients. Different approaches such as the lingual orthodontic technique, clear aligners, or esthetic brackets have been introduced to satisfy esthetic expectations. Esthetic brackets are often used in combination with esthetic arch wires coated with Teflon. However, peeling of the coating material over time results in rough surfaces that are suitable sites for plaque accumulation. Moreover, it has been reported that the surface roughness of esthetic arch wires may reduce the performance of sliding mechanics and mechanical strength, since the exposed core material increases friction coefficient.[1]

Esthetic orthodontic arch wires are available in 2 forms: coated metal wires and nonmetal transparent wires. Epoxy resin, polytetrafluoroethylene (PTFE) (Teflon), parylene (silver polymer), rhodium, and, less frequently,

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palladium are the materials used in the coating of arch wires. Physical properties of coated arch wires vary depending on the thickness of the coating and the manufacturing process.[1-3]

PTFE is a commonly used material for esthetic coating and is known under the name Teflon® from DuPont Co. Teflon is a synthetic polymer consisting of carbon and fluorine. Because of the strength of carbon-fluorine bonds, Teflon is nonreactive, heat resistant, and hydrophobic. In the field of orthodontics, it is known as an anti-adherent and esthetic material with excellent mechanical properties, as well as good mechanical stability.[4-6]

In the literature, the optical, biological, and mechanical properties of esthetic arch wires such as sliding properties, coating stability, force transmission values, color stability, and plaque accumulation have been previously evaluated.[1,7-13] Many of these properties have been reported to be far from the ideals.

Despite their widespread use, in-vivo studies about changes in the surface of PTFE materials are not available in the literature. In addition, color stability has not been investigated in-vivo until today. The aim of this study was to evaluate the surface roughness, microbial plaque retention, and discoloration of Teflon-coated arch wires from 3 different manufacturers.

METHODS

This study was approved by the Ethics Committee of Bezmialem Vakıf University with the decision number 71306642-050.01.04. An informed consent form was signed by all the patients/parents involved in the study. The study was conducted on patients who presented to the Orthodontics Department of Bezmialem Vakıf University for fixed treatment.

The physical and microbiological characteristics of 0.016-inch and 0.016 × 0.022-inch Teflon-coated arch wires of 3 different manufacturers (EverWhite (EW) (American Orthodontics, Sheboygan, USA), Titanol Cosmetic (TC) (Forestadent, Pforzheim, Germany), Proflex (PF) (G&H Orthodontics, Franklin, USA)) were evaluated.

G*Power program was used for power analysis. A sample size calculation based on a pilot study showed that at least 9 specimens per group would be necessary to evaluate the surface roughness (d (effect size): 0.640, SD: 2.7, power: 0.39, and $\alpha = 0.05$) and *Streptococcus mutans* adhesion (d (effect size): 0.638, SD: 0.02, power: 0.39, and $\alpha = 0.05$) and minimum 2 specimens would be required to evaluate the color change (d (effect size): 19.687, SD: 0.13, power: 0.39, and $\alpha = 0.05$). Thus 15 patients were included in each group for possible data loss. Patients with good oral hygiene, no periodontal disease, permanent dentition, no caries, no systemic disease, no antibiotics used, no more than 3 mm of crowding, and who were not smoking were included in the study. All patients were given oral hygiene training by the same researcher, and a standard toothbrush and toothpaste were provided for free.

The arch wires were ligated with elastomeric ligatures (Pearl-colored ligatures, American Orthodontics, Sheboygan, USA)

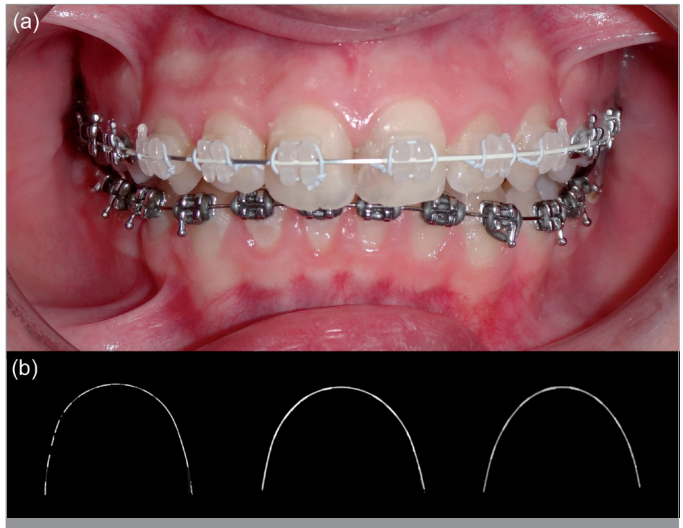

Figure 1. a, b. Intraoral (a) and extraoral (b) images of esthetic arch wires after clinical usage

to 0.018-inch ceramic brackets (Clarity™ ADVANCED Ceramic Brackets; 3M, USA) for anterior teeth and to metallic brackets (Master Brackets; American Orthodontics, Sheboygan, USA) for posterior teeth. Surface roughness and color change data were collected initially (as-received) (T0) and after 28 days of clinical exposure (retrieved) (T1) (Figure 1). One wire was measured for each brand in the control group to assess surface roughness and *S. mutans* adhesion.

An atomic force microscope (AFM) (NT-MDT, Netweaver Solaris, Moscow, Russia) was used in the semi-contact mode to analyze the surface roughness of the as-received and retrieved wire samples. The samples were prepared by cutting 5-mm pieces from one side and the non-curved flat ends of each arch wire. The AFM probe (NT-MDT-NSG01) (curvature radius, 10 nm) with a constant force of 1.45–15.1 N/m was applied on the samples that were fixed to a metal holder. Three surfaces were scanned in 2-mm intervals for each sample with a scanning area of 20 × 20 μm, and the mean surface roughness (Ra) was recorded. For the rectangular wires, measurements were taken from the 0.022-inch surface of the wires.

The *S. mutans* adhesion was investigated on the 15 pieces of each brand. Arch wire pieces of 20 mm in length were cut from the distal ends of the as-received and retrieved wires. The used arch wire pieces were kept in an ultrasonic cleaner for 10 minutes and in distilled water for 10 minutes before the experiment.[13] All the wires were sterilized in the autoclave at 121°C for 15 minutes prior to the experiment.

Fresh cultures were prepared by streaking from −80°C stocks and adding to 5% Sheep Blood Agar, followed by incubation at 37°C with 5% CO_2 for *S. mutans* suspension. After 2–3 days of incubation, single colonies were selected, transferred to Brain Heart Infusion (BHI) broth, and incubated until the optical density of the culture reached 0.5 at 600 nm (Spectrophotometer, U-5100, HITACHI), which corresponds to 1.5×10^8 colony-forming units (cfu)/mL. Bacteria suspension was centrifuged and washed with phosphate-buffered saline (PBS), resuspended in the same

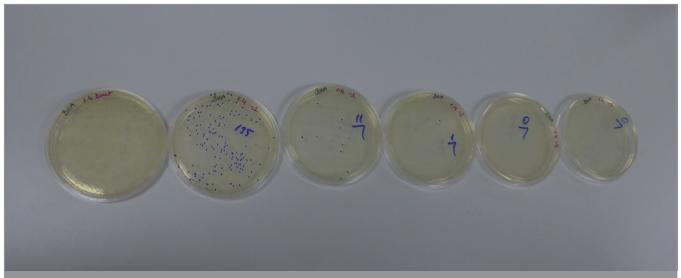

Figure 2. Bacterial colonies after 40 hours incubation of esthetic arch wires

initial volume of the fresh BHI broth. Each arch wire was placed in a 15-mL conical tube in aseptic conditions, and 2 mL of bacteria suspension was added to the tubes. All samples were incubated for 40 hours. One sample from each group was incubated with 2 mL of sterile BHI broth without bacteria for control. Also, Gram stain and Vitek MS analyses were performed with isolated colonies to confirm the purity of the culture. At the end of the incubation period, samples were transferred to a sterile 1.5-mL centrifuge tube and washed 3 times with PBS to remove planktonic bacteria. For enumeration of adherent bacteria, samples were sonicated (Bandelin, SONOPULS), vortexed, and serially diluted until 1:10 000 dilution was achieved. A 100 µL of sample from each dilution was inoculated to a BHI agar plate. Following an appropriate incubation period, colonies were counted, and the number of bacteria in each sample was calculated[9] (Figure 2).

Colorimetric measurements of samples with small dimensions such as arch wires are technically not possible with standard spectrophotometers. Moreover, round surfaces are known to be physically inappropriate for the color analysis. This is the reason why only rectangular arch wires were used for color measurements in a custom-made setting. Since the probe's sensor area is 5 mm wide, a total width of at least 3 mm was required to properly measure the color. Accordingly, in the present study, the setup was modified as described by Inami et al.[14] and 7-wire segments of each brand (11 mm in length, 0.016 × 0.022 inch) were tightly fixed using flowable resin (TetricEvoFlow Dental Flowable Composite, Ivoclar Vivadent, Saint Paul, NY, USA) from both edges.

The initial color of the unused wires was recorded using a VITA Easyshade Compact DEASYC220 (VITA Zahnfabrik, Bad Sackingen, Germany) spectrophotometer with a special tip, which allows repeated measurements in the exact center of the samples.

Then, 2 of the wires in the middle were made removable, and two 11-mm long pieces cut from the flat part of the used wires were seated in the chamber. In this way, the segments of the used wires were placed in the middle of the setup, and 3 pieces of the unused wires were fixed on the right and left sides. The color was measured from the side of the wires facing the occlusal surface (Figure 3).

The color was measured before clinical exposure (T0) and after 28 days of clinical use (T1). The spectrophotometer was calibrated according to the manufacturer's instructions. Each measurement was repeated 3 times, and the mean value was recorded.

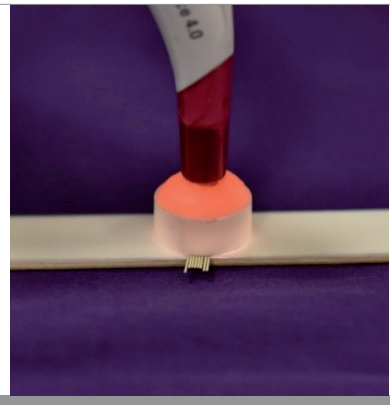

Figure 3. Color measurement of the arch wires

Color measurement was based on the CIE L*a*b* system. Δ*E* values were used to evaluate the color difference. ΔE values were converted to NBS (National Bureau Standards) values, which show clinically important definitions.[15]

Statistical Analysis

The data distribution was evaluated by using Kolmogorov-Smirnov and Shapiro Wilks tests. IBM SPSS for Windows (Version 22.0, IBM SPSS Corp., Armonk, NY, USA) was used for statistical analysis. The mean roughness and bacterial adhesion were compared using one-sample *t*-tests. The effect of coating and wire size on surface roughness and *S. mutans* adhesion were evaluated with the two-way ANOVA test, and the Tukey HSD test was used in post hoc analyses. One-sample *t*-test was used to evaluate the difference in surface roughness between as-received and retrieved wires. Student's *t*-test was used to evaluate the difference in *S. mutans* adhesion between as-received and retrieved wires. The change in continuous data was evaluated by using Pearson's correlation analyses. During the interpretation of the correlation coefficients, the values of 0.0–0.24, 0.25–0.49, 0.50–0.74, and 0.75–1.00 were considered weak, medium, strong, and very strong, respectively. Differences were considered statistically significant when $P < .05$.

RESULTS

Mean Surface Roughness and Biofilm Adhesion

Comparison of the mean surface roughness values (Ra) of the as-received and retrieved wire samples are shown in Table 1. In all groups, the mean surface roughness values were statistically and significantly higher than the initial values. Three-dimensional images of a wire sample before and after clinical use are presented in Figure 4.

The comparison of the surface roughness of the wires based on their manufacturers, based on their dimensions, and the intergroup comparison of the wires having the same brand and the same dimensions are shown in Table 2. Wire dimensions showed to have a statistically significant effect on the surface roughness ($P = .038$; $P < .05$). A detailed comparison of surface roughness for retrieved arch wires based on wire dimensions and manufacturer are shown in Table 3. In this detailed analysis, although there was a statistical difference between round and rectangular

Table 1. Comparison of the surface roughness means of as-received and retrieved arch wires (μm)

	0.016 PF (n = 15)	0.016 × 0.022 PF (n = 15)	0.016 TC (n = 15)	0.016 × 0.022 TC (n = 15)	0.016 EW (n = 15)	0.016 × 0.022 EW (n = 15)
Retrieved (Mean ± SD)	82.03 ± 32.31	107.85 ± 27.68	98.09 ± 27.43	113.27 ± 31.34	100.99 ± 23.89	102.32 ± 16.30
As-received	44.34	25.55	42.00	77.89	9.38	24.98
*P**	.003*	.000*	.000*	.004*	.000*	.000*

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
One-sample t-test, **P* < .05.

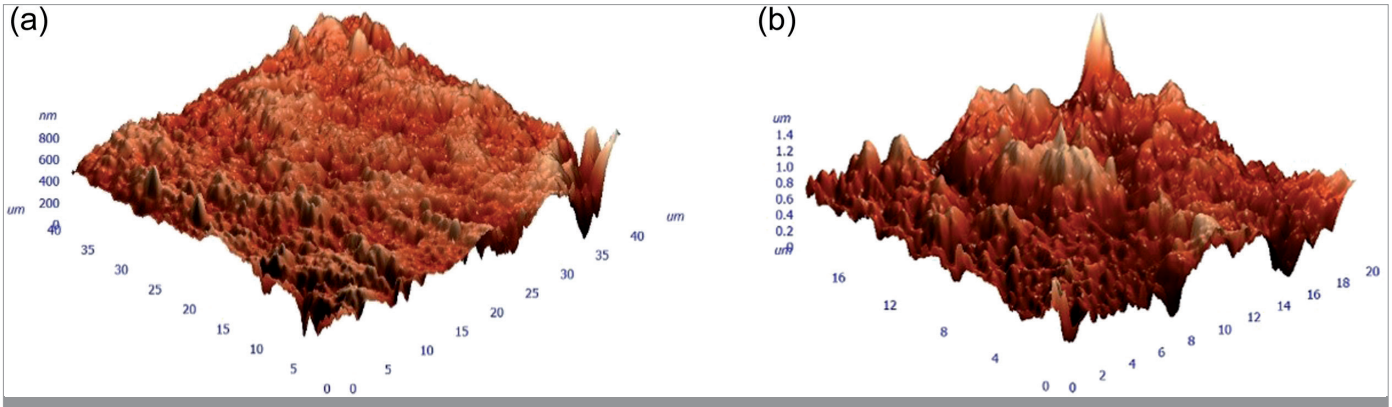

Figure 4. a, b. Atomic force microscopic three-dimensional images before (a, 40 × 40 μm) and after 4 weeks (b, 20 × 20 μm) of clinical usage

PF wires, no significant difference was observed between the other samples ($P = .035$; $P < .05$).

Statistical comparison of *S. mutans* adhesion in the as-received and retrieved arch wires are shown in Table 4. Two brands (PF and TC) showed significant changes after clinical use. *S. mutans* adhesion of rectangular PF wires was weaker after clinical use ($P = .040$; $P < .05$), while the amount of *S. mutans* bacterial adhesion of round TC wires was stronger after clinical use ($P = .005$; $P < .05$). The comparison of *S. mutans* adhesion for retrieved arch wires based on wire dimensions and manufacturer is shown in Table 5. A statistically significant difference was found in *S. mutans* bacterial adhesion of different-branded wires ($P = .000$; $P < .05$). The detailed comparison of the *S. mutans* adhesion based on the manufacturer and the wire dimension is shown in Table 6. No statistically significant difference was found in *S. mutans* adhesion for both round and rectangular wires (PF: $P = .578$; $P > .05$) (TC: $P = .636$; $P > .05$) (EW: $P = .302$; $P > .05$).

The difference between the brands in terms of mean *S. mutans* adhesion was statistically significant for the round ($P = .002$; $P < .05$) and rectangular wires ($P = .048$; $P < .05$) (Table 6). In the post hoc Tukey HSD analysis, a significant difference was noted between the round and rectangular PF and EW wires. The EW showed significantly higher bacterial adhesion compared to PF wires.

Pearson correlation analysis was performed to evaluate whether there was a linear relationship between the mean surface roughness and *S. mutans* adhesion in the arch wires after clinical use (Table 7). No significant correlation was found between the mean surface roughness and *S. mutans* adhesion.

Color Change

ΔE values were calculated at T0 and T1 (Table 8). No statistically significant difference was found between the color measurement values of the rectangular wires of each of the 3 brands at T1 ($P = .203$). To determine the clinical significance of the color change, ΔE values were transformed to NBS units (Table 9).

Table 2. Comparison of the surface roughness means based on the manufacturer and the wire dimension (μm)

Source	Type III Sum of Squares	df	Mean Square	F	*P*
Manufacturer	1294.193	2	647.097	0.886	.417
Wire Dimension	3285.43	1	3285.43	4.500	.038*
Manufacturer × Wire Dimension	1658.32	2	829.16	1.136	.328

Two-way ANOVA test, **P* < .05.

Table 3. Comparison of surface roughness for retrieved arch wires based on wire dimensions and manufacturer (μm)

	Wire Dimensions		
	0.016	0.016 × 0.022	
Manufacturer	Mean ± SD	Mean ± SD	*P*
PF	82.03 ± 32.31	107.85 ± 27.68	.035*
TC	98.09 ± 27.43	113.27 ± 31.34	.241
EW	100.99 ± 23.89	102.32 ± 16.3	.880
P	0.250	0.617	

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite; SD, standard deviation.
Two-way ANOVA test, **P* < .05.

Table 4. Comparison of the *Streptococcus mutans* bacterial colony-forming unit values of as-received and retrieved arch wires (log10) (cfu/mL)

	0.016 PF (Mean ± SD)	0.016 × 0.022 PF (Mean ± SD)	0.016 TC (Mean ± SD)	0.016 × 0.022 TC (Mean ± SD)	0.016 EW (Mean ± SD)	0.016 × 0.022 EW (Mean ± SD)
Retrieved arch wires	3.77 ± 0.44	3.89 ± 0.52	4.03 ± 0.52	4.13 ± 0.5	4.46 ± 0.19	4.36 ± 0.23
As-received arch wires	3.93 ± 0.50	4.52 ± 0.51	3.45 ± 0.16	4.14 ± 0.40	4.35 ± 0.42	4.35 ± 0.42
P	.529	.040*	.005*	.969	.458	.941

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Student's t-test, *$P < .05$.

According to the NBS values, a clinically noticeable color change was observed in the TC and EW wires. On the other hand, the PF wires showed a very significant color change. According to the clinical color matching reported by O'Brien,[16] the Δ*E* values obtained in all groups in this study can be classified as clinically noticeable.

DISCUSSION

Orthodontic arch wires are coated with the PTFE material for esthetic purposes. There are studies showing that this material reduces bacterial adhesion, but there are also studies defending just the opposite.[17-19] Moreover, a controversial condition is that the surface of the coating material can be roughened over time and cannot maintain its surface integrity because of high mechanical forces resulting from oral functions.[20] Water, which is known as a plasticizer in the saliva, affect resistance to sliding in aesthetic orthodontic wires coated with Teflon.[21] It has also been reported that proteins adhere quickly and irreversibly to roughened PTFE coatings.[22,23] As a result, peeling and coloration of esthetic arch wires can result in failure to meet esthetic expectations of patients. Considering the studies in the literature, we can maintain that there is no consensus on the contribution of PTFE in biofilm formation on esthetic orthodontic arch wires. Most of the studies in this field have been carried out in-vitro, and the color stability of this commonly used material has not yet been investigated in-vivo.

In clinical practice, the same bracket type is not used for every patient, and patients present with different amounts of crowding. In this study, we took precautions aiming to standardize the factors affecting the amount of peeling of the arch wires. Standard bracket types were used for the patients participating in the study. The severity of crowding changes the insertion angle of the wire to the bracket slot, which may increase the amount of friction and consequently result in more peeled-off material. Moreover, plaque accumulation increases when crowding is severe because the maintenance of oral hygiene becomes harder. This is the reason why patients with mild crowding (less than 3 mm) were included in the study. Training on oral hygiene maintenance was offered to all the patients verbally by the same researcher, and a toothbrush and toothpaste kit was given for free.

Surface Roughness and Biofilm Adhesion

In the literature, various devices have been used to measure the surface roughness of arch wires such as surface profilometry,

Table 5. Comparison of the *Streptococcus mutans* adhesion based on the manufacturer and the wire dimension (log10) (cfu/mL)

Source	Type III Sum of Squares	df	Mean Square	F	*P*
Manufacturer	3.782	2	1.891	10.475	.000*
Wire size	0.029	1	0.029	0.162	.689
Manufacturer × wire size	0.157	2	0.078	0.434	.650

Two-way ANOVA test, *$P < .05$.

Table 6. Comparison of *Streptococcus mutans* adhesion for retrieved arch wires based on wire dimensions and manufacturer (log10) (cfu/mL)

	Wire Dimensions		
	0.016	0.016 × 0.022	
Manufacturer	Mean ± SD	Mean ± SD	*P*
PF	3.77 ± 0.44[a]	3.89 ± 0.52[a]	.578
TC	4.03 ± 0.52[ab]	4.13 ± 0.50[ab]	.636
EW	4.46 ± 0.19[b]	4.36 ± 0.23[b]	.302
P	.002*	.048*	

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Two-way ANOVA test; *$P < .05$. Note: Different letters (a and b) in the columns show the difference between groups.

Table 7. Correlation between mean surface roughness and *Streptococcus mutans* adhesion

Groups		Mean Surface Roughness and *S. mutans* Adhesion
0.016 PF (n = 15)	r	−.021
	P	.952
0.016 × 0.022 PF (n = 15)	r	−.326
	P	.327
0.016 TC (n = 15)	r	.025
	P	.943
0.016 × 0.022 TC (n = 15)	r	−.471
	P	.144
0.016 EW (n = 15)	r	.150
	P	.659
0.016 × 0.022 EW (n = 15)	r	−.046
	P	.893

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
Pearson correlation test. This text denotes if there is a correlation relatinship between mean surface roughness and S. Mutans adhesion.

Table 8. Comparison of color change (Δ*E*) of rectangular arch wires

	0.016 × 0.022 PF (n = 15)					0.016 × 0.022 TC (n = 15)					0.016 × 0.022 EW (n = 15)					
	Mean	SD	Median	Min.	Max.	Mean	SD	Median	Min.	Max.	Mean	SD	Median	Min.	Max.	*P*
Δ*E*	9.56	0.92	9.25	8.04	10.79	5.78	8.62	2.93	1.24	31.33	6.35	2.54	5.20	4.64	12.08	.203

PF, Proflex; TC, Titanol Cosmetic; EW, EverWhite.
One-way ANOVA test, $^{*}P < .005$; $^{***}P < .001$.

atomic force microscopy, and laser spectroscopy.[2,12,24] Bourauel et al.[24] reported that there were high similarities between all these 3 methods.[25] The AFM device has many advantages, such as providing quantitative values for the assessment of surface roughness, requiring no additional preparation processes, and providing high resolution in the production of 3D images. A major disadvantage is that the surface of a sample cannot be analyzed as a whole, because the scanning speed is slow and the scanning area is small. In the present study, to be able to make accurate measurements with the AFM's probe, the wire samples were prepared by cutting 5-mm long pieces from the straight distal ends of the arch wires, instead of the curved anterior parts. The samples were prepared by taking into consideration the areas where the surface coating remained intact. Nevertheless, AFM is considered to be a reliable technique for evaluating the surface quality of orthodontic arch wires.[26,27] Because of the mentioned disadvantages of AFMs, one might object to relying only on a single method to assume about the total surface topography of arch wires. The fact that surface roughness was measured from a small area where the surface coating kept its integrity was a major methodologic limitation in our study. This is, in fact, a limitation in any study evaluating the surface roughness of arch wires.

S. mutans adherence to orthodontic materials has been accepted as an important factor for the pathogenesis of enamel demineralization during orthodontic treatment.[28,29] Since *S. mutans* increase during orthodontic treatment and because it has high cryogenic activity, we decided to include *S. mutans* in our study.[30] Taha et al.[9] evaluated the *in vitro* biofilm formation on rectangular esthetic NiTi arch wires. After 4 and 8 weeks of clinical use, they evaluated surface roughness and *in vivo* biofilm formation on the wires. The authors reported the presence of a positive correlation between surface roughness and biofilm adhesion. Although Taha et al.[9] measured the surface roughness in a similar way, the wires were removed from the mouth and the number of bacteria was measured immediately after.[9] However, in the current study, the wires were sterilized and placed into a culture medium that was prepared by the researchers, and no correlation was found between the surface roughness and biofilm adhesion. The difference may be explained by the difference in methods and the brand of the wires tested in the studies. In addition, this study can be criticized for inter-patient oral microflora differences. In our study, standardized culture media were preferred since the specific oral bacteria counts can change from patient to patient. Moreover, one of the wires tested by Taha et al.[9] had only labial surface coating while the wires tested in our study had all surfaces coated with Teflon.[9]

Table 9. Conversion of Δ*E* to NBS values

Arch Wires	Δ*E* Values	NBS Values
0.016 × 0.022 PF (n = 15)	9.56 ± 0.92	8.79 ± 0.84
0.016 × 0.022 TC (n = 15)	5.78 ± 8.62	5.31 ± 7.9
0.016 × 0.022 EW (n = 15)	6.35 ± 2.54	5.84 ± 2.3
NBS unit = Δ*E* × 0.92		

NBS, National Bureau Standards.

Elayyan et al.[1] reported that the surface roughness of epoxy-coated NiTi arch wires increased after 33 days of clinical use. It was reported that 25% of the coating disappeared and the metallic surface was exposed.[1] In the current study, all the wires showed noticeable peeling after clinical use, but the amount of missing coating was not quantitatively evaluated. It was noticed that the core material was less exposed in the segments of the wires inserted to the brackets in all groups. The Ra parameter increased in all groups after clinical use in a way that would significantly affect the biofilm formation as described by Quirynen et al.[22] A previous study reported that the highest amount of coating lost was in EW arch wires.[31] In our study, after clinical use, the increase in Ra values was higher in the rectangular PF wires compared to that in the unused counterparts.

Previous studies have reported that small variations in surface roughness have no significant effect on bacterial adhesion. There are also factors such as free surface energy and physicochemical properties that affect bacterial adhesion on dental materials.[31] This study has reported results that are consistent with the results of our study; that is, no significant correlation was found between the surface roughness and bacterial adhesion in orthodontic materials.

There are differences in the surface roughness of coated wires among different brands. The chemical composition of the coating material and the production technique are the factors affecting the surface properties of orthodontic wires.[32] In our study, although the coating material was the same in all groups, the difference in surface roughness values before and after clinical use might be explained with production method differences that are not fully explained by the manufacturers. The cross-sectional dimension of the core metal may vary depending on the coating material to reach the final arch wire thickness. This is another factor that may explain the non-uniform peeling of arch wires coated with the same material.[33] The thickness of the coating material of the wires used in our study is unknown. The companies suggest that they produce standard cross-sectional arch wires; however, the thickness of the coating is not something disclosed.

Color Change

Da Silva et al.[34] conducted a study on esthetic arch wires after 21 days of clinical use and reported the shortness of the oral exposure period as a limitation of their study. Similar to the findings of da Silva et al.[34] none of the esthetic arch wires used in our study presented ideal features after 28 days of clinical use. The surface roughness values measured on the remaining coatings showed significant increases compared to the as-received counterparts. The number of clinical trials in the literature to which we can compare our findings remains insufficient.

The color change is one of the physical changes that occur in esthetic arch wires following clinical exposure. We used ΔE^* values to evaluate the perceptibility of the color differences referring to previous studies.[17,35] The NBS rating system provides absolute criteria by which the ΔE^* values can be converted into definitions with clinical significance.[15] ΔE values below 3.7 are not visually noticeable and are considered to be clinically acceptable.[36] Douglas et al.[37] reported that approximately 50% of dentists could detect a color difference of 2.6 ± 3 units. In our study, ΔE values were 5.78 for the TC wires, 6.35 for the EW wires, and 9.56 for the PF wires. High ΔE values show that significant color changes occurred in all the PTFE arch wire groups.

One of the limitations of our study is the fact that the patients had different eating and drinking habits. Some patients preferred softer food items, while others preferred harder food items that could have caused more peeling. In addition, the acidity of consumed foods or toothbrush trauma caused by the patients might have affected the coating material integrity. The patients were given standard toothpastes and toothbrushes to standardize the erosive silica concentration in the pastes. However, the hand pressure was not, and cannot be, a parameter that could be standardized. Different coloring properties of consumed foods and liquids may affect the color stability.

CONCLUSION

Statistically significant increases were recorded in the surface roughness values of the clinically used wires. A statistically significant difference was noted between the initial *S. mutans* bacterial adhesion amounts of the different brands of arch wires. According to NBS units, a clinically noticeable color change was observed in the TC and EW wires, while a significant color change was observed in the PF wires. There was no significant correlation between the mean surface roughness and microbiological measurement values.

In the light of these findings, further clinical studies are required on factors affecting the integrity of coating material of esthetic arch wires. The physical features of the commercially available esthetic wires need to be ameliorated.

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Informed Consent: An informed consent form was signed by all the patients/parents involved in the study.

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REFERENCES

1. Elayyan F, Silikas N, Bearn D. Ex vivo surface and mechanical properties of coated orthodontic archwires. *Eur J Orthod*. 2008;30(6):661-667. [CrossRef]
2. Zegan G, Sodor A, Munteanu C. Surface characteristics of retrieved coated and nickel-titanium orthodontic archwires. *Rom J Morphol Embryol*. 2012;53(4):935-939.
3. Kim Y, Cha JY, Hwang CJ, Yu HS, Tahk SG. Comparison of frictional forces between aesthetic orthodontic coated wires and self-ligation brackets. *Korean J Orthod*. 2014;44(4):157-167. [CrossRef]
4. Haryani J, Ranabhatt R. Contemporary esthetic orthodontic archwires: a review. *J Dent Mater Tech*. 2016;5:125-130.
5. Farronato G, Maijer R, Carìa MP, Esposito L, Alberzoni D, Cacciatore G. The effect of Teflon coating on the resistance to sliding of orthodontic archwires. *Eur J Orthod*. 2012;34(4):410-417. [CrossRef]
6. Mousavi SM, Shamohammadi M, Rastegaar Z, Skini M, Rakhshan V. Effect of esthetic coating on surface roughness of orthodontic archwires. *Int Orthod*. 2017;15(3):312-321. [CrossRef]
7. Chng CK, Foong K, Gandedkar NH, Chan YH, Chew CL. A new esthetic fiber-reinforced polymer composite resin archwire: a comparative atomic force microscope (AFM) and field-emission scanning electron microscope (FESEM) study. *Prog Orthod*. 2014;15(1):39. [CrossRef]
8. da Silva DL, Mattos CT, de Araújo MVA, de Oliveira Ruellas AC. Color stability and fluorescence of different orthodontic esthetic archwires. *Angle Orthod*. 2013;83(1):127-132. [CrossRef]
9. Taha M, El-Fallal A, Degla H. In vitro and in vivo biofilm adhesion to esthetic coated arch wires and its correlation with surface roughness. *Angle Orthod*. 2016;86(2):285-291. [CrossRef]
10. Akın M, İleri Z, Aksakallı S, Başçiftçi FA. Mechanical properties of different aesthetic archwires. *Turk J Orthod*. 2014;27(2):85-89. [CrossRef]
11. Argalji N, Silva EMD, Cury-Saramago AC, Mattos CT. Characterization and coating stability evaluation of nickel-titanium orthodontic esthetic wires: an in vivo study. *Braz Oral Res*. 2017;31:e68. [CrossRef]
12. da Silva DL, Mattos CT, Simáo RA, de Oliveira Ruellas AC. Coating stability and surface characteristics of esthetic orthodontic coated archwires. *Angle Orthod*. 2013;83(6):994-1001. [CrossRef]
13. Rongo R, Ametrano A, Gloria A, et al. Effects of intraoral aging on surface properties of coated nickel-titanium archwires. *Angle Orthod*. 2013;84(4):665-672. [CrossRef]
14. Inami T, Tanimoto Y, Minami N, Yamaguchi M, Kasai K. Color stability of laboratory glass-fiber-reinforced plastics for esthetic orthodontic wires. *Korean J Orthod*. 2015;45(3):130-135. [CrossRef]
15. Koksal T, Dikbas I. Color stability of different denture teeth materials against various staining agents. *Dent Mater J*. 2008;27(1):139-144. [CrossRef]
16. O'Brien WJ. Orthodontic wire. In: O'Brien WJ, ed. Dental materials and their selection. Chicago: Quintessence Pub Co; 2008. [CrossRef]
17. Berry JA, Biedlingmaier JF, Whelan PJ. In vitro resistance to bacterial biofilm formation on coated fluoroplastic tympanostomy tubes. *Otolaryngol Head Neck Surg*. 2000;123(3):246-251. [CrossRef]

18. Demling A, Elter C, Heidenblut T, et al. Reduction of biofilm on orthodontic brackets with the use of a polytetrafluoroethylene coating. *Eur J Orthod*. 2010;32(4):414-418. [CrossRef]
19. Elter C, Heuer W, Demling A, Hannig M, Heidenblut T, Stiesch M. Comparative analysis of biofilm formation on dental implant abutments with respect to supra- and subgingival areas: polytetrafluoroethylene versus titanium. *Int J Prosthodont*. 2011;24(4):373-375.
20. Hellemann CF, Grade S, Heuer W, Dittmer MP. Three-dimensional analysis of initial biofilm formation on polytetrafluoroethylene in the oral cavity. *J Orofac Orthop Fortschr Kieferorthop*. 2013;74:458-467.
21. Lin CY, Kim JS, Lin ET, Lin ET. Prolonged water immersion alters resistance to sliding of aesthetic orthodontic coated wires. *Orthod Craniofac Res*. 2021;24(1):111-120. [CrossRef]
22. Quirynen M, Bollen CML, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. *Int J Oral Maxillofac Implants*. 1996;11(2):169-178.
23. Rupp F, Axmann D, Ziegler C, Geis-Gerstorfer J. Adsorption/desorption phenomena on pure and Teflon® AF-coated titania surfaces studied by dynamic contact angle analysis. *J Biomed Mater Res*. 2002;62(4):567-578. [CrossRef]
24. Rudge P, Sherriff M, Bister D. A comparison of roughness parameters and friction coefficients of aesthetic archwires. *Eur J Orthod*. 2015;37(1):49-55. [CrossRef]
25. Bourauel C, Fries T, Drescher D, Plietsch R. Surface roughness of orthodontic wires via atomic force microscopy, laser specular reflectance, and profilometry. *Eur J Orthod*. 1998;20(1):79-92. [CrossRef]
26. Lee GJ, Park KH, Park YG, Park HK. A quantitative AFM analysis of nano-scale surface roughness in various orthodontic brackets. *Micron*. 2010;41(7):775-782. [CrossRef]
27. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. *J Mater Sci Mater Med*. 2007;18(1):155-163. [CrossRef]
28. Øgaard B. Prevalence of white spot lesions in 19-year-olds: a study on untreated and orthodontically treated persons 5 years after treatment. *Am J Orthod Dentofacial Orthop*. 1989;96(5):423-427. [CrossRef]
29. O'reilly MM, Featherstone JD. Demineralization and remineralization around orthodontic appliances: an in vivo study. *Am J Orthod Dentofacial Orthop*. 1987;92(1):33-40. [CrossRef]
30. Lee SP, Lee SJ, Lim BS, Ahn SJ. Surface characteristics of orthodontic materials and their effects on adhesion of mutans streptococci. *Angle Orthod*. 2009;79(2):353-360. [CrossRef]
31. Bradley TG, Berzins DW, Valeri N, Pruszynski J, Eliades T, Katsaros C. An investigation into the mechanical and aesthetic properties of new generation coated nickel-titanium wires in the as-received state and after clinical use. *Eur J Orthod*. 2014;36(3):290-296. [CrossRef]
32. D'Antò V, Rongo R, Ametrano G, et al. Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. *Angle Orthod*. 2012;82(5):922-928. [CrossRef]
33. Kaphoor AA, Sundareswaran S. Aesthetic nickel titanium wires--how much do they deliver? *Eur J Orthod*. 2012;34(5):603-609. [CrossRef]
34. da Silva DL, Mattos CT,San'tAnna EF. Cross-section dimensions and mechanical properties of esthetic orthodontic coated archwires. *Am J Orthod Dentofac Orthop*. 2013;143(suppl 4):S85-91. [CrossRef]
35. Filho HL, Maia LH, Araújo MV, Eliast CN, Ruellas AC. Colour stability of aesthetic brackets: ceramic and plastic. *Aust Orthod J*. 2013;29(1):13-20.
36. Eliades T, Gioka C, Heim M, Eliades G, Makou M. Color stability of orthodontic adhesive resins. *Angle Orthod*. 2004;74(3):391-393. [CrossRef]
37. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. *J Prosthet Dent*. 2007;97(4):200-208. [CrossRef]