REVISTA DE ODONTOLOGIA DA UNESP

ORIGINAL ARTICLE

Rev Odontol UNESP. 2017 Sept-Oct; 46(5): 307-311
Doi: http://dx.doi.org/10.1590/1807-2577.02317

Color stability of esthetic coatings applied to nickel-titanium archwires

Estabilidade de cor de revestimentos estéticos aplicados em fios de níquel-titânio

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Resumo

Introdução: A estabilidade de cor é uma característica importante quando da utilização de fios com revestimentos estéticos. **Objetivo:** Avaliar, por meio de um estudo *in vitro*, as alterações de cor na superfície de fios ortodônticos estéticos de níquel-titânio, revestidos por teflon (Ortho Organizers, EUA) ou resina epóxi (Tecnident, Brasil), quando em contato com solução de corante. **Material e método:** Foram utilizados 12 segmentos de 20 mm de comprimento para cada tipo de revestimento, os quais foram montados em dois corpos de prova com a largura de 7 mm. Os fios foram submetidos à avaliação da superfície vestibular quanto à fluorescência e à leitura colorimétrica inicial e após a imersão em solução de corante por 21 dias, utilizando o espectrofotômetro digital portátil VITA Easyshade® Compact. Alterações na diferença de cor total de acordo com o tipo de revestimento foram verificadas utilizando-se teste o T para amostras independentes ($p<0.05$). As características da superfície dos revestimentos, nos fios originais, foram avaliadas por meio do microscópio eletrônico de varredura. **Resultado:** Verificou-se que o revestimento estético sofreu alteração de cor e a diferença foi estatisticamente significante entre os grupos. A análise da superfície demonstrou falhas como: desgaste, depressões, elevações, falta de material, granulações, ranhuras e trincas e falta de padronização na aplicação do revestimento nos fios da mesma marca comercial, sendo essas menos evidentes nos revestimentos de resina epóxi. **Conclusão:** Os revestimentos estéticos não apresentaram estabilidade de cor e, dentre os tipos, os de teflon evidenciaram alteração mais intensa que os de resina epóxi.

Descritores: Fios ortodônticos; estética dentária; fluorescência.

Abstract

Introduction: Color stability is an important feature to be considered when using esthetic coated archwires. **Objective:** To evaluate color changes on the surface of esthetic nickel-titanium archwires coated with Teflon (Ortho Organizers, USA) or epoxy resin (Tecnident, Brazil) after immersion in staining solution. **Material and method:** Twelve 20-mm-long wire segments were used for each type of coating, which were mounted as two test specimens with a width of 7 mm each. The buccal surface of the archwires was evaluated for fluorescence and color measurements both at baseline and after immersion in a staining solution for 21 days using the VITA Easyshade® Compact spectrophotometer (Model DEASYC220). Differences in total color change according to coating type were compared using an independent samples *t*-test ($p<0.05$). The surface characteristics of as-received coated archwires were assessed using scanning electron microscopy. **Result:** Color changes were observed on the esthetic coatings, with a significant difference between the two brands analyzed. Surface analysis revealed flaws such as wear, pitting, elevations, lack of material, granulation, grooves, cracks, and lack of standardization in the coating process in all as-received archwires, but flaws were less evident in epoxy-resin coatings. **Conclusion:** The two esthetic coatings did not show color stability, but Teflon coatings showed a more intense color change than epoxy-resin coatings.

Descriptors: Orthodontic wires; dental esthetics; fluorescence.

INTRODUCTION

The basic principles of Orthodontics are facial esthetics, stability, functional efficiency, and periodontal tissue health[1]. Of these, esthetics is the main reason for seeking treatment. An increase in the number of adults seeking orthodontic treatment has given rise to concerns about the appearance of the orthodontic appliance and the perceived esthetic impact that it may have on patients' quality of life[2].

Esthetic brackets have been introduced in the market as a substitute for metal brackets to meet such a demand, and are now widely accepted[3,4]. In addition to brackets and elastic ligatures, esthetic archwires have been produced, such as metal wires coated with epoxy resin or Teflon (polytetrafluoroethylene) of tooth-like color and fiber reinforced plastic (FRP) wires, which are made from translucent composite materials comprising a methyl methacrylate polymer matrix and reinforcing glass fibers[5,6].

Advantages have been described for as-received coated archwires, such as reduced surface roughness and friction[6]. However, some disadvantages have also been pointed out, such as poor durability of the coating in the oral environment, color changing, cracking and pitting, increased surface roughness, and predisposition to a buildup of amorphous organic matter through the mechanical action of masticatory forces and tooth brushing as well as due to the effects of oral enzymes[7-11]. Therefore, further studies are needed to analyze the real applicability of esthetic archwires in clinical practice.

The present study aimed to evaluate, by means of *in vitro* analysis, the color stability of Teflon and epoxy-resin coatings applied to nickel-titanium archwires after immersion in staining solution and the surface characteristics of as-received coated archwires.

MATERIAL AND METHOD

Nickel-titanium orthodontic archwires with cross-section dimensions of 0.019 x 0.025" and esthetic Teflon (polytetrafluoroethylene) or epoxy-resin coating were evaluated (Table 1).

Sample size calculation was based on an alpha significance level of 5% (0.05) and beta of 20% (0.20) and a power of 80% to detect a minimum difference in color change of ΔE* 1.7 (with a standard error deviation of 0.59), which is in agreement with the study of da Silva et al.[11], and indicated that six test specimens would be required per group. A pilot study with two specimens of each brand revealed that wire diameter was too small for the reading capacity of the tip of the spectrophotometer. Hence, test specimens for fluorescence analysis should be produced by fixing together six wire segments.

Hence, six test specimens of each brand were prepared, each consisting of six 20-mm-long wire segments that were placed together and had their ends fixed with ethyl cyanoacrylate (SuperBonder, Loctite, Company, Brasil) with the buccal side up, for a total width of at least 7 mm per sample. The samples were identified by a label facing the surface to be analyzed and attached to the end of a 0.010" braided metal ligature wire (Morelli, Sorocaba, SP, Brazil) with a length of 10 cm.

The test specimens were stored in distilled water at 37°C for 24 hours. Then, the specimens were blotted dry and their buccal surface was evaluated for fluorescence and the initial color measurements were made using the VITA Easyshade® Compact spectrophotometer (Model DEASYC220; VITA Zahnfabrik, Bad Säckingen, Germany), which was held perpendicular to the surface of the test specimen. Color measurements were performed on each specimen in a completely dark room (Darkroom at the Dental Clinic of our institution).

The archwires were placed on an extraoral photography mirror (BaraschSylmar, São Paulo, SP, Brazil) to avoid the influence of the background[12]. A holder was used to standardize the positions of the mirror, spectrophotometer and light source for all color readings so that the tip of the spectrophotometer was in contact with the center of the test specimen surface.

Staining solution preparation and staining procedure

A coffee solution (Maratá, Taphrina, SE, Brazil) was used for staining, which was prepared by dissolving 15 g of coffee in 500 mL of boiling distilled water[13,14]. The solution was stirred for 10 seconds every 30 minutes until cooled to 37°C, then filtered through filter paper (Maratá), placed in an appropriate container, and incubated at 37°C throughout the experiment. To reduce the precipitation of coffee particles, the solution was stirred once a day for 1 minute.

The test specimens were immersed in the coffee solution for 3 hours a day for 21 days, and the solution was changed every 7 days. Every day, after the daily immersion time of 3 hours, the specimens were removed from the solution, rinsed with distilled water for 5 minutes, dried with tissue paper, and restored in distilled water at 37°C until the next daily treatment. The inicial pH of the staining solution was 5.0. To reduce precipitation of coffee particeles, the solution was shaken once a day for 1 minute.

Evaluation of color stability

The color of the esthetic coated archwires was measured using the *Commission Internacionale de I'Eclairage* (CIE)[15] *L*a*b** color space relative to CIE standard illuminant D65, which divides the color by means of a mathematical process of colorimetric curve into three fields: L* or ΔL*, which indicates lightness or color values (from black to white); a* or Δa*, which indicates hue on a green (–) to red (+) axis; and b* or Δb*, which indicates hue on a blue (–) to yellow (+) axis.

Color measurements were performed at baseline and after 21 days of staining. Three measurements were performed for each test specimen at each time point. After three color readings, the spectrophotometer was calibrated according to the manufacturer's instructions. The average of three readings taken for each parameter (L*, a*, and b*) in each test specimen was calculated and recorded. Color changes were calculated using the following equation: $\Delta E^* = [(\Delta L)2 + (\Delta a)2 + (\Delta b)2]1/2$, where ΔL, Δa and Δb are the difference between the initial and final L*, a* and b* values at 21 days of immersion.

To relate the amount of color change (ΔE*) recorded by the spectrophotometer to a clinical condition, the data were converted

Table 1. Characteristics of the esthetic nickel-titanium archwires used in the study

Manufacturer	Cross-section dimension	Coating type	Coating surface	Total segments
Ortho Organizers, Inc., San Marcos, CA, USA	0.019 x 0.025"	Teflon	Total	6
Tecnident, São Carlos, SP, Brazil	0.019 x 0.025"	Epoxy resin	Total	6

into National Bureau of Standards (NBS) units using the following equation: NBS units = ΔE* x 0.92, where critical remarks of color differences were expressed in terms of NBS units[16]. These values are shown in Table 2.

Evaluation of surface characteristics of as-received coated archwires using scanning electron microscopy (SEM)

The micromorphological surface characteristics of as-received coated archwires were assessed quantitatively and descriptively using SEM (JEOL model JSM-6460 LV, Tokyo, Japan). For this purpose, six 4-mm wire segments were used in each group. The specimens were mounted on aluminum stubs by cathodic sputtering and coated with gold. The analysis was performed at a voltage of 20 kV and magnification of 90x, 200x, and 500x up to 1000x.

We assessed the quality and standardization of the esthetic coating process in the as-received archwires. This micromorphological surface characterization was performed qualitatively by two examiners who were blinded to which brand was being analyzed. In case of disagreement about the type of flaw observed, a third examiner was invited and disagreements were resolved by consensus. Examiners were previously calibrated by assessing two wire segments of each group until reaching an agreement on the flaws observed in esthetic coatings.

Statistical analysis

The color change (ΔE*) values were statistically analyzed using Biostat, version 5.3 (Belém, PA, Brazil). The Kolmogorov-Smirnov test was used to assess the normality of data distribution and homogeneity of the sample ($p=0.075$), with a significance level of 5% ($p<0.05$). Between-group differences in color change were compared using an independent samples *t*-test. Differences between mean values were considered significant if $p<0.05$.

Table 2. Color changes according to the National Bureau of Standards (NBS) system

NBS unit	Definitions of color changes	
0.0-0.5	Trace	Extremely slight change
0.5-1.5	Slight	Slight change
1.5-3.0	Noticeable	Noticeable change
3.0-6.0	Appreciable	Marked change
6.0-12.0	Much	Extremely marked change
12.0 or more	Very much	Change to another color

RESULT

Table 3 shows the total color difference (ΔE*) between groups in esthetic coated archwires at baseline and after 21-day immersion in staining solution, using an independent samples *t*-test, and color change converted into NBS unit. Color changes were observed on the esthetic coating of archwires of the two brands analyzed, with a statistically significant difference in color change between groups. When the values were converted into NBS units, the Teflon-coated archwires (Ortho Organizers) showed a greater color change, characterized by change to another color.

All as-received coated archwires showed flaws in the coating process, as demonstrated by SEM. The flaw types most commonly observed on the esthetic coatings were wear, pitting, elevations, lack of material, granulation, grooves, and cracks. However, coating application failures were more evident in esthetic archwires coated with Teflon than in those coated with epoxy resin (Figure 1).

DISCUSSION

The esthetic demands of adult patients in relation to orthodontic appliances has prompted the industry not only to develop esthetic ligatures and other accessories, which have evolved greatly in terms of physical, mechanical and optical properties, but also to produce orthodontic archwires that mimic the natural color of teeth without jeopardizing clinical performance due to changes in their mechanical properties or induction of cytotoxic effects[6,8-10,17]. In this context, the color stability of esthetic coatings applied to orthodontic archwires is also of great clinical relevance.

There is still no consensus as to the ideal method for identifying color changes, but it is common sense that visual color comparison is a very subjective method. In order to reduce the degree of subjectivity, a spectrophotometer was used in the present study because it distinguishes each color scale. In addition, color measurements using a spectrophotometer provide a more consistent assessment and greater reproducibility of results[18-20].

Color changes were described according to the CIE *L*a*b** (or CIELAB) parameters[15]. The CIE *L*a*b** color space is currently one of the most commonly used mechanisms for color measurement, being particularly suitable for the measurement of slight color changes. In previous studies[16,19,20], varying interpretations of ΔE* have been

Table 3. Means (standard deviations) of total color difference (ΔE*) between groups after 21-day immersion in staining solution and color change converted into NBS unit

Group	Initial ΔE^1	After 21 days ΔE^2	ΔE^* ($\Delta E^2 - \Delta E^1$)	p	NBS unit	Color change
Tecnident (n=6)	23.4 (8.8)	33.05 (5.12)	9.65		8.87	Extremely marked change
				0.042		
Ortho Organizers (n=6)	20.56 (4.46)	49.24 (3.66)	28.68		26.38	Change to another color

Bold indicates statistically significant differences between means ($p<0.05$; independent samples *t*-test).

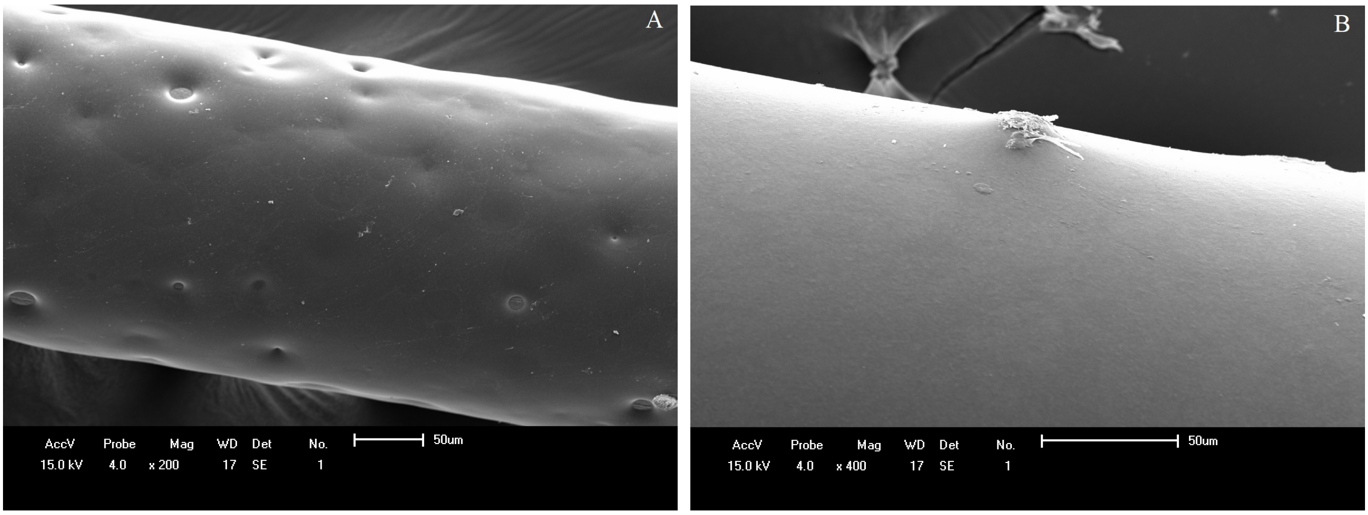

Figure 1. Photomicrographs of as-received coated archwires: (A) Ortho Organizers; (B) Tecnident.

used to quantify the perceived color differences. This led us to use, based on the study of da Silva et al.[11], the NBS rating system, which is characterized by the ability to eliminate these divergences, since ΔE* values are converted into a scale of color variation in which changes are described by terms that facilitate clinical application.

Regarding the choice of staining solution, previous studies[11,18-20] indicate that coffee is the most chromogenic agent compared to other substances, such as tea and coke. In addition, an attempt was made to simulate a contact time of the staining agent with the archwire as closely as possible to what would occur clinically. For this purpose, the daily contact time of the coffee solution with the archwire was reduced to 3 hours, instead of leaving the specimen immersed in the solution for 21 days continuously.

The results showed that the staining solution affected the color stability of esthetic coatings, regardless of the type of coating (Teflon or epoxy resin). Quantitatively, the magnitude of color change was greater and statistically significant in Teflon-coated archwires (OrthoOrganizers). These findings are consistent with those of da Silva et al.[11], who also observed absence of color stability in coated archiwires of different brands. However, the magnitude of color change was not associated with type of coating.

The SEM analysis of as-received coated archwires revealed, in addition to lack of standardization in the coating process, several types of flaws, such as wear, pitting, elevations, lack of material, granulation, grooves, and cracks, consistent with the findings of Zegan et al.[9] and da Silva et al.[11]. However, epoxy-resin coatings had a more uniform surface than Teflon coatings. These flaws may have been a contributing factor for retention of pigments on the surface, facilitating staining.

Thus, although these both Teflon and epoxy-resin coatings have been developed to improve the esthetics of nickel-titanium archwires, their color changed after immersion in staining solution por 21 dias, which, along with the known loss of coating material in the oral environment,[7,11] could greatly compromise the esthetics of orthodontic appliances, requiring archwires to be changed every monthly visit. The time when the most significant color change occurs may be assessed in clinical studies.

CONCLUSION

- Esthetic coatings showed color changes when in contact with a staining solution for a 21-day period;
- Of the two types of coating tested in this study, Teflon coatings showed a more intense color change than epoxy-resin coatings;
- The SEM surface analysis revealed flaws such as wear, pitting, elevations, lack of material, granulation, grooves, cracks, and lack of standardization in the coating process in as-received coated archwires of the same brand, but these flaws were less evident in epoxy-resin coatings than in Teflon coatings.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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Received: March 21, 2017
Accepted: October 19, 2017