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Does the use of antioxidant agents after dental bleaching compromise the aesthetic results of ceramic laminate veneers?

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ABSTRACT

Purpose: This *in vitro* study aimed to evaluate the aesthetic compromise generated in adhesive interface of ceramic laminate veneer luted after tooth bleaching and the use of antioxidant agents. Thus, the chromatic coordinates and whitening index (WI_D) were evaluated, comparing whiteness changes (ΔWI_D) results to perceptibility and acceptability thresholds.

Material and methods: In total, 88 bovine enamel samples (7 × 8 × 4 mm; n = 8) were submitted to the ceramic laminate veneer luting protocol according to surface treatment (unbleached and bleached enamel), antioxidant agents (control; 10% ascorbic acid and 10% α-tocopherol), and luting periods (after 24 h and after 14 days). To lute IPS e.max ceramic restorations (7 × 8 × 0.6 mm), Tetric N-Bond Universal adhesive system and Variolink Aesthetic LC resin cement were used. An ultraviolet–visible spectrophotometer (UV–VIS) was utilized to measure CIE L*a*b* coordinates prior to and after UV-B artificial accelerated aging for 252, 504, and 756 h. L*, a*, and b* axes were evaluated separately, and the whitening stability (ΔWI_D) effect was assessed by varying the whiteness index for dentistry (WI_D). The 50:50% visual threshold was used to evaluate ΔWI_D values (whiteness perceptibility [WPT] and whiteness acceptability [WAT]). Color parameters changes (ΔL*Δa*Δb*), WI_D, and ΔWI_D data were subjected to 2-way repeated measures ANOVA followed by Tukey's test (α = 0.05).

Results: Different UV-aging periods influenced the chromatic coordinates, WI_D, and ΔWI_D of the ceramic restorations regardless of the bleaching treatment, antioxidant solutions and luting periods ($P < .05$). In general, ΔWI_D values after UV-aging periods were above perceptibility and acceptability thresholds (WPT = 0.72 and WAT = 2.62, respectively) for all experimental groups ($P < .05$). Unbleached and 10% ascorbic acid-treated enamels luted after 14 days of the antioxidant action exhibited lower ΔL* and Δb* values, while control group showed lower Δa* values. All experimental groups showed similar performance on ΔWI_D compared to the control group, regardless of the UV-aging period analyzed ($P > .05$).

Conclusion: α-tocopherol is a suitable antioxidant solution to be used 24 h post enamel bleaching not compromising clinical acceptability of ceramic laminate veneers.

Clinical relevance: The adhesive interface of ceramic laminate veneers may appear darker after the use of antioxidant agents affecting the clinical acceptability of the restorations.

1. Introduction

The development of CAD/CAM (computer-aided design and computer-aided manufacturing) technology and luting agent materials has led to the performance of minimally invasive Dentistry. (Strazzi-Sahyon et al., 2022) The combination of these concepts with new ceramic materials has provided a satisfactory way to obtain high aesthetics, predictability, strength, and longevity of oral rehabilitations, (Arif et al., 2019) in addition to the possibility of designing, milling, and luting ceramic restorations in one session, simplifying and reducing cost

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and chairside time. (Araujo and Perdigão, 2021) Lithium disilicate is a satisfactory ceramic choice to associate with CAD/CAM technology and resin-based luting agents because of its optical properties, chemical durability, mechanical and resistance properties, high translucency, biocompatibility (Ottoni et al., 2022; Aragonez et al., 2022) and natural aesthetics. In addition, its combination with resin-based cements allows mimicry of texture, color, and shape, providing a harmonious smile. (Strazzi-Sahyon et al., 2020a) All these factors enable minimally invasive treatment with ceramic laminate veneers luted to dental substrate, with no or minimal wear. (Strazzi-Sahyon et al., 2019; Strazzi Sahyon et al., 2018) However, dental bleaching prior to luting of ceramic laminate veneers could be necessary, as the chroma intensity of the underlying tooth substrate combined with the ultrathin ceramic restorations may interfere in the final result. (Strazzi-Sahyon et al., 2022, 2023)

In-office and at-home dental bleaching procedures vary in relation to the bleaching agent type, its concentration and action time, and irradiation light association. (Machado et al., 2016) However, the release of oxygen as the main product of the reaction is a common factor for both techniques. (Cintra et al., 2016) An immediate adverse effect of clinical importance on bond strength of resin-based restorations to bleached dental substrate is related to the residual oxygen and hydrogen peroxide remaining in the interprismatic region, that hinder the infiltration of resinous monomers and their polymerization. (Briso et al., 2014; Freire et al., 2009; Khamverdi et al., 2016) To overcome this condition, some authors suggest a delay of approximately 7–28 days before the restorations are performed, as the bond strength after the bleaching procedure is time-dependent. (Vidhya et al., 2011; Souza-Gabriel et al., 2020)

Some methods have been proposed to reverse and neutralize the oxidative effects of hydrogen peroxide on the bond strength, reducing the waiting time to lute ceramic restorations, such as the use of reducing compounds and antioxidant agents, including ascorbic acid and α-tocopherol. (Khamverdi et al., 2016; Morris et al., 2001; Alkhudhairy et al., 2018; Sasaki et al., 2009) Strazzi-Sahyon HB et al. (Strazzi-Sahyon et al., 2022) claim that the α-tocopherol improved the shear bond strength and interface sealing of ceramic laminate veneer restorations and did not alter the morphology and chemical composition of tooth substrate. (Strazzi-Sahyon et al., 2022) Furthermore, Strazzi-Sahyon et al. (2023) demonstrated that the use of α-tocopherol solution after dental bleaching was able to reverse the oxidizing effects of hydrogen peroxide, and did not influence the mechanical properties, such as nanohardness, elastic modulus, and degree of conversion of the bonding interface components of ceramic restorations. (Strazzi-Sahyon et al., 2023) The authors also observed that its use after bleaching process did not promote color change on the aged-ceramic restorations' interfaces. (Strazzi-Sahyon et al., 2023) However, the lack of thorough research and discussion on the changes in chromatic coordinates and whiteness (ΔWI_D) in relation to aesthetic parameters, taking into account perceptibility (WPT) and acceptability (WAT) thresholds, necessitates the gathering of additional data before considering these solutions for clinical use.

Conforming to the latest guidance on color assessments published by the International Organization for Standardization (ISO/TR 28642:2016), (International Organization for Standardization, 2016; Pérez et al., 2019; Pérez Mdel et al., 2016) color stability after aging, staining, or post bleaching procedures should be evaluated on the basis of 50:50% acceptability (AT: $\Delta E_{ab} = 2.7$ and $\Delta E_{00} = 1.8$) and 50:50% perceptibility (PT: $\Delta E_{ab} = 1.2$ and $\Delta E_{00} = 0.8$) thresholds. In this manner, if the absolute color difference evaluated before and after aging is at or below PT, it means an excellent match; if the difference is between PT and AT, it means an acceptable match; and if the difference is above AT, it means an unacceptable match. (Vidal et al., 2020) In addition, WI_D variations (ΔWI_D) can be measured through comparison with 50:50% perceptibility and acceptability thresholds for whiteness (WPT = 0.72; and WAT = 2.62, respectively) (Pérez et al., 2019; Pérez Mdel et al., 2016). Thus, whiteness variation changes lower than 0.72 WI_D units would not be perceptible to an average observer. In this context, data on the color variation of the isolated chromatic coordinates (ΔL*, Δa*, and Δb*) and the whiteness index for dentistry (ΔWI_D), comparing the results with the perceptibility and acceptability thresholds may increase the evidence on the clinical viability of the treatment using the antioxidants.

If the α-tocopherol antioxidant effectiveness on optical properties of ceramic restorations over time is proven, an effective luting protocol after dental bleaching could be established. Thus, this *in vitro* study aimed to evaluate the aesthetic compromise generated in adhesive interface of ceramic laminate veneers luted after tooth bleaching and the use of antioxidant agents subjected to UV-accelerated artificial aging on the chromatic coordinates (ΔL*, Δa*, and Δb*) and whiteness changes (ΔWI_D), comparing ΔWI_D results to perceptibility and acceptability thresholds. The null hypotheses tested were that chromatic coordinates and whiteness changes (ΔWI_D) of the adhesive interface would not be influenced by 1) the bleaching process and antioxidant agents, and 2) aging periods, considering WPT and WAT thresholds as references.

2. Material and methods

2.1. Specimen preparation

This study was submitted and approved by the Local Institutional Ethics Committee on the Use of Animals (#01058-17). Table 1 provides details of the materials assessed in this study.

Eighty-eight lithium disilicate veneers (7 × 8 × 0.6 mm) were made from lithium disilicate blocks, (shade A1-HT, IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) using a low-speed diamond saw installed in a cutter machine (Isomet 1000; Buehler, Lake Bluff, IL, USA) under constant water irrigation. The ceramic restorations were crystallized in the manufacturer's furnace (Programat EP 5000; Ivoclar

Table 1
Data on materials explored regarding their classification, chemical composition, and batch numbers.

Material	Classification	Chemical Composition	Batch Number
Whiteness HP Maxx 35% (FGM)	Bleaching Agent	Thickeners, dye mixture, glycol, inorganic filler, deionized water, 35% hydrogen peroxide.	031218
Ascorbic Acid – Solution (Apothicário)	Vitamin C	Ascorbic acid at 10% and 2.5% alcohol, adjustment of pH = 7.0 with triethanolamine (yellowish color).	–
α – Tocopherol – Solution (Apothicário)	Vitamin E	α-tocopherol at 10% and 2.5% alcohol, adjustment of pH = 7.0 with triethanolamine (grayish color).	–
Tetric N Bond Universal (Ivoclar Vivadent)	Adhesive System	HEMA, 10-MDP, Bis-GMA, MCAP, D3MA, ethanol, water, highly dispersed silicon dioxide, photoinitiator.	X25012
Variolink Aesthetic LC (Ivoclar Vivadent)	Light-Cured Resin Cement	Bis-GMA, UDMA, TEGDMA, ytterbium trifluoride, boroaluminofluorosilicate glass, spheroidal mixed oxide, benzoylperoxide, stabilizers, pigments, ivocerin as initiator Volume of inorganic fillers: 38%, 60–68%.	X43425
Monobond N (Ivoclar Vivadent)	Silane Agent	Ethanol, 3-trimethoxysilyl-propyl methacrylate, 10-MDP, disulfide acrylate	X17917

Abbreviations: HEMA, 2-hydroxyethylmethacrylate; 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; Bis-GMA, bisphenol-A glycidyl methacrylate; MCAP, methacrylated carboxylic acid polymer; D3MA, decandiol dimethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

Vivadent, Schaan, Liechtenstein) at 850 °C during 35 min, following the manufacturer's instructions. (Strazzi-Sahyon et al., 2023)

Initially, a total of 200 bovine teeth were used, from cattle aged 2.5–3.0 years; (Wang et al., 2021; Soares et al., 2016) teeth that presented stains, wide incisal loss, morphological crown alteration, and cracks/fractures on the enamel substrate were replaced. The teeth were mechanically cleaned using periodontal curettes, followed by prophylaxis with pumice stone and water. Subsequently, a magnifying glass at a magnification of × 4 (Bio-Art Equipamentos Odontológicos Ltda, São Carlos, SP, Brazil) was used to identify cracks and/or fractures induced by the tooth extraction. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) The teeth were subjected to an initial reading of L* using the Easyshade spectrophotometer (Vita-Zahnfabrik, Germany), following the CIELab system (Commission International de L'Eclairage L*a*b system). After obtaining the L* values, the median of all samples was calculated, then eighty-eight teeth presenting L* values closer to the median with a tolerance of 5% were selected.

A transversal section was performed 1.0 mm above the cementum-enamel junction to separate the anatomic crowns from the roots using a low-speed diamond saw under water irrigation, connected to an Isomet 1000 (Buehler, Lake Bluff, IL, USA). (Strazzi-Sahyon et al., 2022, 2023) Four sections were performed on the anatomic crown, two in the cervico-incisal direction at a distance of 8 mm, and another two in the mesial-distal direction, 7-mm apart, obtaining an enamel block of 7 × 8 × 4 mm. (Strazzi-Sahyon et al., 2022, 2023) The buccal surfaces of the enamel blocks were abraded and flattened under water cooling using #600 grit silicon carbide papers (Buehler, Lake Bluff, IL, USA). (Strazzi-Sahyon et al., 2022, 2023) The enamel samples were randomly distributed into 11 experimental groups (n = 8), according to the bleaching procedure (bleached and unbleached enamel), antioxidant agents (control, 10% ascorbic acid, and 10% α-tocopherol), and luting periods of the ceramic restorations (after 24 h and after 14 days), as described in Table 2.

2.2. Experimental groups

In the control group, the enamel substrate was etched using 37% phosphoric acid (FGM, Joinville, SC, Brazil) for 30 s, followed by rinsing and drying with deionized water and air jets, respectively. A layer of adhesive system (Tetric N-Bond Universal; Ivoclar Vivadent, Schaan, Liechtenstein) was actively applied on the etched enamel surface for 20 s, followed by air jets for 5 s to evaporate the solvent. The adhesive system layer was polymerized for 10 s using a multiple peak light-curing unit (VALO; Ultradent, South Jordan, UT, USA), in standard mode (1000 mW/cm^2). (Strazzi-Sahyon et al., 2022, 2023) The inner surface of lithium disilicate was etched for 20 s with 5% hydrofluoric acid (FGM, Joinville, SC, Brazil), and the residues from the ceramic etching were cleaned with a water/air spray, and dried with air jets. The silane agent (Monobond Plus; Ivoclar Vivadent, Schaan, Liechtenstein) was actively applied onto the etched ceramic for 60 s and air-dried for 5 s. A layer of adhesive system (Tetric N-Bond Universal; Ivoclar Vivadent, Schaan, Liechtenstein) was then actively applied for 20 s, followed by air jets for 5 s to evaporate the solvent, without polymerization. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) The neutral shade light-cured resin cement (Variolink Aesthetic; Ivoclar Vivadent, Schaan, Liechtenstein) was dispensed on the inner lithium disilicate surface, avoiding bubble formation, and the ceramic restoration was placed on the enamel surface. Prior to the restoration polymerization, a load of 4.9 N was positioned on the restoration assembly to standardize the luting agent thickness, and removed thereafter. The overflow resin cement was eliminated using a microbrush, and the assembly was polymerized using a multiple peak light-curing unit (VALO – standard mode; Ultradent, South Jordan, UT, USA) for 30 s in an opaque black box to hamper external light interference. The distance between the sample surface and light tip was standardized to 1 mm. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018)

Table 2
Division of the experimental groups.

Groups Abbreviation	Group Treatment Detail
Control	Luting of ceramic laminate veneers onto enamel surface unbleached and non-treated with antioxidant agents
AA-24H	Luting of ceramic laminate veneers onto unbleached enamel surface after 24 h of 10% ascorbic acid antioxidant application
AA-14D	Luting of ceramic laminate veneers onto unbleached enamel surface after 14 days of 10% ascorbic acid antioxidant application
αT-24H	Luting of ceramic laminate veneers onto unbleached enamel surface after 24 h of 10% α-tocopherol antioxidant application
αT-14D	Luting of ceramic laminate veneers onto unbleached enamel surface after 14 days of 10% α-tocopherol antioxidant application
BLE-24H	Luting of ceramic laminate veneers onto bleached enamel surface after 24 h associated with no antioxidant agents
BLE-14D	Luting of ceramic laminate veneers onto bleached enamel surface after 14 days associated with no antioxidant agents
BLE-AA-24H	Luting of ceramic laminate veneers onto bleached enamel surface after 24 h of 10% ascorbic acid antioxidant application
BLE-AA-14D	Luting of ceramic laminate veneers onto bleached enamel surface after 14 days of 10% ascorbic acid antioxidant application
BLE-αT-24H	Luting of ceramic laminate veneers onto bleached enamel surface after 24 h of 10% α-tocopherol antioxidant application
BLE-αT-14D	Luting of ceramic laminate veneers onto bleached enamel surface after 14 days of 10% α-tocopherol antioxidant application

The AA-24H group specimens were treated as described for the control group; however, 24 h before the restoration luting, the treatment with 20 μL of 10% ascorbic acid antioxidant solution (Apothicário, Araçatuba, SP, Brazil) was carried out using a calibrated syringe. (Strazzi-Sahyon et al., 2022, 2023) The antioxidant agent remained in contact with the enamel substrate for 15 min, followed by rinsing and drying with deionized water and air jets, respectively. (Strazzi-Sahyon et al., 2022, 2023) The specimens were kept in light-proof recipients containing artificial saliva (pH = 7.0; Apothicário, Araçatuba, SP, Brazil) at 37 °C. The AA-14D group specimens were treated similarly to the descriptions for the previous group; however, the ceramic luting was carried out 14 days after the antioxidant agent action. The αT-24H and αT-14D group specimens were treated similarly to the descriptions for the AA-24H and AA-14D groups, respectively; however, the treatment with 20 μL of 10% α-tocopherol antioxidant solution (Apothicário, Araçatuba, SP, Brazil) was carried out.

The BLE-24H group specimens were bleached with 35% hydrogen peroxide (Whiteness HP Maxx; FGM, Joinville, SC, Brazil), mixing one drop of thickener with three drops of peroxide. Subsequently, 40 μL of the mixed product was placed on the enamel surface using a calibrating syringe (FD10006; Sinapse Biotecnologia, São Paulo, SP, Brazil); and the bleaching product was maintained in contact with the enamel surface for 15 min and removed using sterile cotton and absorbent paper. (Strazzi-Sahyon et al., 2022, 2023) The peroxide product was applied three times, totaling 45 min of exposure to bleaching agent. The enamel surface was then rinsed and dried with deionized water and air jets, respectively. The bleaching procedure was carried out three times, with an interval of one week between each session, during which the specimens were kept in artificial saliva (pH = 7.0) at 37 °C. (Strazzi-Sahyon et al., 2022, 2023) At the end of the third bleaching session, the specimens were rinsed and dried with deionized water and air jets, respectively. Then, 24 h post enamel bleaching, the ceramic laminate luting procedure was performed as described above.

The BLE-14D group specimens were treated similarly to the descriptions for BLE-24H group; however, the luting of ceramic restoration was carried out 14 days after the bleaching procedure. The BLE-AA-24H, BLE-AA-14D, BLE-αT-24H, and BLE-αT-14D group specimens were treated similarly to the descriptions for AA-24H, AA-14D, αT-24H, and

αT-14D, respectively; however, the enamel surfaces were bleached beforehand by the hydrogen peroxide action. All specimens were kept in light-proof recipients containing Hanks solution (Sigma Chemical Co., St. Louis, MO, USA) at 37 °C for 24 h (Strazzi-Sahyon et al., 2022)

2.3. Analysis of chromatic coordinates change (ΔL*Δa*Δb*)

The specimens were submitted to initial color readings using a UV–visible (VIS) spectrophotometer (model UV-2450; Shimadzu, Kyoto, Japan) and CIEL*a*b* System. Standardization of the specimen insertion into the color analysis device was carried out through demarcation on the posterior portion of each sample. Five measurements were evaluated for each specimen using a black silicon matrix (L* = 4.05; a* = - 0.16; and b* = - 0.08), and the arithmetic mean was obtained. (Strazzi-Sahyon et al., 2019, 2023; Strazzi Sahyon et al., 2018)

After the initial color readings, the specimens were submitted to a UV-accelerated artificial aging procedure using a UV-accelerated aging chamber (EQUV; Equilam, Diadema, SP, Brazil). Eight fluorescent lamps (40 W each; emission peak of 313 nm) were coupled to the aging machine according to ASTM G154 (American Society for Testing Materials, Standard 154). (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) Alternate periods of UV light and condensation with distilled water were carried out under conditions of heat and 100% relative humidity, simulating the natural aging process in the oral cavity. Each aging cycle was carried out during 12 h; in the first 8 h the samples were irradiated by UV lights at 60 ± 3 °C, and in the following 4 h, a condensation stage without light irradiation at 45 ± 3 °C was performed. (Strazzi-Sahyon et al., 2019, 2020a, 2023; Strazzi Sahyon et al., 2018) Each complete aging period was composed of 21 cycles (168 h of UV-B irradiation exposure and 84 h of condensation). (Strazzi-Sahyon et al., 2019, 2020a, 2023; Strazzi Sahyon et al., 2018) The aging process was carried out three times (252, 504, and 756 h), and color readings were measured after each aging cycle. The chromatic coordinates change (ΔL*Δa*Δb*) values were obtained after each UV-B aging period using the baseline chromatic coordinates. The specimens were kept in Hanks solution (Sigma Chemical Co., St. Louis, Missouri, USA) at 37 °C until the color readings were performed. (Strazzi-Sahyon et al., 2019, 2020a, 2023; Strazzi Sahyon et al., 2018)

2.4. Whiteness Index for dentistry (WI_D)

The whiteness index for dentistry (WI_D) is a CIELab-based index with a linear formulation and the values were obtained using the following formula [1]: (Pérez Mdel et al., 2016)

$$WI_D = 0.511L^* - 2.324a^* - 1.100b^* \quad [1]$$

The 50:50% perceptibility level was determined at 0.72 (WPT = 0.72) while 50:50% acceptability level was determined at 2.62 (WAT = 2.62). (Pérez et al., 2019; Pérez Mdel et al., 2016) Lower WI_D values indicate darker samples, and a negative ΔWI_D demonstrates that the specimens presented lower WI_D values than the previous evaluation, while higher WI_D values indicate whiter samples, and a positive ΔWI_D demonstrates that the specimens showed higher WI_D values than the previous evaluation. (Vidal et al., 2020)

2.5. Statistical analysis

Data from WI_D, color parameters changes (ΔL*Δa*Δb*), and ΔWI_D were subjected to the homogeneity test (Levene; Jamovi Program; Version 2.2.5), and thus analyzed using two-way repeated measures analysis of variance (ANOVA; Jamovi Program; Version 2.2.5). The Tukey post hoc test was used to identify differences among groups using a global significance level of 95%.

3. Results

3.1. Whiteness Index for dentistry (WID)

The WI_D values are listed in Table 3. WI_D values of the BLE-αT-24H group were higher than those of control, AA-24H, αT-24H, αT-14D, and BLE-14D groups before aging process (baseline) (P < .05) (Table 3). For the first and second aging periods (252 and 504 h, respectively), there were no differences among the experimental groups (P > .05). However for the third aging period (756 h), the BLE-αT-14D group showed lower WI_D values compared to αT-24H, BLE-AA-24H, and BLE-AA-14D experimental groups (P < .05), while AA-24H group presented lower WI_D values only compared to αT-24H group (P = .041) (Table 3).

Regarding the aging periods, there were no differences between the baseline and 252 h period of aging for all experimental groups (P > .05), except for the AA-14D, BLE-αT-24H, and BLE-αT-14D groups, for which the 252 h period showed lower WI_D values than baseline (P < .05) (Table 3). Baseline promoted higher WI_D values compared to 504 and 756 h periods of aging for control, AA-24H, BLE-αT-24H, and BLE-αT-14D groups (P < .05). αT-24H, αT-14D, and BLE-AA-14D groups did not show statistical differences in WI_D values comparing the baseline and aging periods (P > .05) (Table 3). In general, there were no differences comparing the first period of aging with the second and third periods for all experimental groups simultaneously (P > .05), except for AA-24H, BLE-14D, BLE-αT-24H, and BLE-αT-14D groups (P < .05). Comparing the second and third aging periods, only the BLE-αT-14D group presented a statistical difference, as 504 h promoted higher WI_D values than 756 h (P = .018) (Table 3).

3.2. Color coordinate L* variation (ΔL*)

The ΔL* values are shown in Table 4. ΔL* values of BLE-14D group were higher than those of control, AA-14D, αT-24H, and BLE-αT-24H groups in first aging period (P < .05) (Table 4). Furthermore, the AA-14D group presented a statistical difference compared to all experimental groups (P < .05), except for control, αT-24H, and BLE- αT-24H groups (P > .05). For second aging period, the BLE-αT-14D group promoted higher ΔL* values compared to the AA-14D and BLE-αT-24H

Table 3
Mean and standard deviation values of whiteness index (WI_D) as a function of the experimental groups and aging periods.

Experimental Groups	Periods			
	Before Aging	252 Hours	504 Hours	756 Hours
Control	30.17 ± 2.10 Ba	28.34 ± 2.40 Aab	25.38 ± 2.61Ab	25.21 ± 2.72 ABCb
AA-24H	30.50 ± 3.42 Ba	30.25 ± 2.41 Aa	26.62 ± 2.24 Ab	24.37 ± 1.72 BCb
AA-14D	33.01 ± 1.82 ABa	28.56 ± 1.92 Ab	25.08 ± 1.48 Ab	27.84 ± 4.07 ABCab
αT-24H	31.33 ± 3.70 Ba	29.33 ± 2.59 Aa	28.86 ± 3.13 Aa	30.41 ± 1.66 Aa
αT-14D	31.41 ± 2.88 Ba	28.80 ± 2.13 Aa	27.62 ± 2.34 Aa	26.60 ± 2.95 ABCa
BLE-24H	31.77 ± 3.68 ABa	29.96 ± 1.94 Aab	26.49 ± 4.65 Ab	27.84 ± 1.62 ABCab
BLE-14D	31.32 ± 1.88 Bab	31.74 ± 1.81 Aa	26.98 ± 2.01 Ab	27.96 ± 2.04 ABCab
BLE-AA-24H	33.45 ± 2.94 ABa	31.25 ± 2.87 Aab	28.69 ± 1.94 Ab	30.02 ± 1.74 ABab
BLE-AA-14D	33.78 ± 2.48 ABa	31.58 ± 0.83 Aa	29.14 ± 1.43 Aa	29.85 ± 4.70 ABa
BLE-αT-24H	37.65 ± 3.17 Aa	31.96 ± 1.29 Ab	27.71 ± 2.34 Ac	27.51 ± 2.95 ABCbc
BLE-αT-14D	33.71 ± 2.88 ABa	29.23 ± 2.03 Ab	28.25 ± 0.68 Ab	23.17 ± 3.67 Cc

Different letters, uppercase in column and lowercase in row, indicate statistically significant differences (P < .05).

Table 4
Mean and standard deviation values of color coordinate L* variation (ΔL^*) of chromatic measurement as a function of the experimental groups and aging periods.

Experimental Groups	Periods		
	252 Hours	504 Hours	756 Hours
Control	1.58 ± 3.70 BCa	- 5.71 ± 3.94 ABCa	- 4.82 ± 6.73 BCa
AA-24H	6.84 ± 2.64 ABa	- 1.88 ± 4.23 ABCb	- 5.85 ± 5.07 BCb
AA-14D	−4.26 ± 3.27 Ca	- 9.95 ± 4.49 Ca	- 7.83 ± 4.64 Ca
αT-24H	5.13 ± 3.65 BCa	0.45 ± 7.22 ABCa	4.93 ± 10.05 ABa
αT-14D	5.85 ± 3.67 ABa	- 0.88 ± 6.32 ABCa	- 1.46 ± 4.52 ABCa
BLE-24H	10.52 ± 8.76 ABa	2.87 ± 7.88 ABb	7.95 ± 6.17 Aab
BLE-14D	14.88 ± 1.11 Aa	3.32 ± 4.60 ABb	5.13 ± 4.60 ABb
BLE-AA-24H	9.54 ± 6.71 ABa	4.24 ± 7.29 ABa	8.27 ± 5.29 Aa
BLE-AA-14D	10.95 ± 4.99 ABa	3.02 ± 5.53 ABb	- 0.66 ± 6.01 ABCb
BLE-αT-24H	3.85 ± 4.50 BCa	- 6.55 ± 5.26 BCb	- 6.41 ± 6.73 BCb
BLE-αT-14D	6.75 ± 5.12 ABa	5.54 ± 7.13 Aa	2.93 ± 7.36 ABCa

Different letters, uppercase in column and lowercase in row, indicate statistically significant differences (P < .05).

groups (P < .05), while the AA-14D group did not promote a statistical difference compared to control, AA-24H, αT-24H, αT-14D, and BLE-αT-24H groups (P > .05) (Table 4). The BLE-AA-24H group resulted in higher ΔL^* values than control, AA-24H, AA-14D, and BLE-αT-24H groups when evaluating the third period of aging (P < .05). Furthermore, the AA-14D group did not present a significant difference for the following experimental groups: control, AA-24H, αT-14D, BLE-AA-14D, BLE-αT-24H, and BLE-αT-14D (P > .05) (Table 4).

Comparing the aging periods, in general, 252 h of artificial accelerated aging promoted higher ΔL^* values than 504 and 756 h for AA-24H, BLE-24H, BLE-14D, BLE-AA-14D, and BLE-αT-24H groups (P < .05) (Table 4). However, no significant differences were observed for control, AA-14D, αT-24H, αT-14D, BLE-AA-24H, and BLE-αT-14D groups (P > .05). Furthermore, no differences were noted between the second and third periods of aging for all experimental groups evaluated (P > .05) (Table 4).

3.3. Color coordinate a* variation (Δa^*)

The Δa^* values are described in Table 5. For the first aging period, AA-14D group yielded higher Δa^* values than control (P = .018) and BLE-AA-24H (P = .029) groups (Table 5). Regarding the second artificial accelerated aging period, the AA-14D group promoted higher Δa^* values compared to control, αT-24H, αT-14D, and BLE-AA-14D groups (P < .05). There were no statistical differences among all experimental groups for the third aging period (P > .05) (Table 5). Comparing the aging periods, there were no differences for any experimental groups evaluated (P > .05), except for the BLE-αT-14D group, in which 756 h of aging promoted higher Δa* values compared to 252 h (P < .001) and 504 h periods (P = .037) (Table 5).

Table 5
Mean and standard deviation values of color coordinate a* variation (Δa^*) of chromatic measurement as a function of the experimental groups and aging periods.

Experimental Groups	Periods		
	252 Hours	504 Hours	756 Hours
Control	0.84 ± 0.15 Ba	0.86 ± 0.29 Ba	1.13 ± 0.26 Aa
AA-24H	0.97 ± 0.27 ABa	1.06 ± 0.33 ABa	1.21 ± 0.36 Aa
AA-14D	1.41 ± 0.42 Aa	1.76 ± 0.37 Aa	1.58 ± 0.76 Aa
αT-24H	1.02 ± 0.15 ABa	0.99 ± 0.28 Ba	1.24 ± 0.59 Aa
αT-14D	1.02 ± 0.37 ABa	0.83 ± 0.46 Ba	1.22 ± 0.28 Aa
BLE-24H	1.12 ± 0.33 ABa	1.22 ± 0.61 ABa	1.43 ± 0.38 Aa
BLE-14D	1.19 ± 0.36 ABa	1.22 ± 0.42 ABa	1.22 ± 0.33 Aa
BLE-AA-24H	0.86 ± 0.20 Ba	1.08 ± 0.41 ABa	1.16 ± 0.51 Aa
BLE-AA-14D	1.14 ± 0.16 ABa	0.95 ± 0.36 Ba	1.12 ± 0.36 Aa
BLE- αT-24H	1.05 ± 0.18 ABa	1.14 ± 0.38 ABa	1.44 ± 0.33 Aa
BLE-αT-14D	1.21 ± 0.12 ABb	1.27 ± 0.15 ABb	1.90 ± 0.11 Aa

Different letters, uppercase in column and lowercase in row, indicate statistically significant differences (P < .05).

3.4. Color coordinate b* variation (Δb^*)

The Δb^* values are presented in Table 6. For the first aging period, the BLE-AA-14D, BLE- αT-24H, and BLE-αT-14D groups promoted higher Δb^* values than control, AA-24H, AA-14D, and αT-24H groups (P < .05) (Table 6). Furthermore, the BLE-24H, BLE-14D, and BLE-AA-24H groups showed higher Δb^* values compared to control, AA-24H, and AA-14D groups (P < .05), while the AA-14D yielded lower Δb^* values than αT-24H (P = .010) and αT-14D (P < .001) (Table 6). Evaluating the second and third aging periods, the BLE-αT-14D group promoted higher Δb^* values than control, AA-24H, AA-14D, αT-24H, and αT-14D groups (P < .05) (Table 6).

Comparing the aging periods, there were no statistical differences in Δb^* values for the following experimental groups: control, AA-24H, AA-14D, BLE-24H, BLE-14D, BLE-AA-14D, BLE- αT-24H, and BLE-αT-14D (P > .05) (Table 6). However, for the αT-24H and αT-14D groups, 252 h of artificial accelerated aging promoted higher Δb^* values than 504 h (P < .05); while for the BLE-AA-14D group, 252 h of aging yielded higher Δb^* values than 756 h (P < .001) (Table 6).

3.5. Whiteness index variation (ΔWID)

The ΔWI_D values are presented in Table 7. The BLE-αT-24H group showed lower ΔWI_D values than the AA-24H and BLE-14D groups in the first aging period (P < .05), while for the second aging period, the BLE-αT-24H group yielded lower values compared only to αT-24H (P = .006) (Table 7). For 756 h of artificial accelerated aging, the αT-24H showed higher ΔWI_D values than BLE-αT-24H (P = .001) and BLE-αT-14D (P < .001). Furthermore, the BLE-14D group yielded higher ΔWI_D values compared to the BLE-αT-14D group in the third aging period (P = .049) (Table 7).

When comparing the aging periods, it can be noted that there were no differences for the following groups: control, αT-24H, αT-14D, BLE-AA-24H, and BLE-AA-14D (P > .05) (Table 7). For the AA-24H and BLE-αT-24H groups, the first aging period showed higher ΔWI_D values compared to the second and third periods, simultaneously (P < .05). However, for the AA-14D, BLE-24H, and BLE-14D groups, 252 h of artificial accelerated aging promoted higher ΔWI_D values only compared to 504 h (P < .05), not presenting statistical differences to 756 h (P > .05). The opposite occurred for BLE-αT-14D, for which 252 h of aging promoted higher ΔWI_D values only compared to 756 h (P < .001), although not presenting significant differences to 504 h (P = .999)

Table 6
Mean and standard deviation values of color coordinate b* variation (Δb^*) of chromatic measurement as a function of the experimental groups and aging periods.

Experimental Groups	Periods		
	252 Hours	504 Hours	756 Hours
Control	0.63 ± 1.18 CDa	- 0.11 ± 1.08 EFa	- 0.11 ± 1.60 CDa
AA-24H	1.37 ± 1.26 CDa	0.41 ± 1.52 CDEFa	0.30 ± 1.37 BCDa
AA-14D	- 0.91 ± 2.36 Da	- 1.12 ± 2.52 Fa	- 2.29 ± 3.17 Da
αT-24H	2.03 ± 1.15 BCa	0.35 ± 1.65 DEFb	0.51 ± 2.82 BCDab
αT-14D	2.93 ± 1.13 ABCa	1.28 ± 1.18 BCDEFb	1.11 ± 1.53 BCDab
BLE-24H	4.18 ± 1.31 ABa	3.56 ± 2.39 ABCDa	4.26 ± 1.40 ABa
BLE-14D	4.02 ± 0.78 ABa	2.91 ± 1.20 ABCDEa	2.87 ± 1.35 ABCa
BLE-AA-24H	4.62 ± 1.81 ABa	4.02 ± 1.50 ABa	4.51 ± 1.00 ABa
BLE-AA-14D	4.69 ± 0.73 Aa	3.62 ± 1.41 ABCab	0.89 ± 4.03 BCDb
BLE- αT-24H	4.74 ± 1.19 Aa	3.58 ± 1.77 ABCa	3.19 ± 1.68 ABCa
BLE-αT-14D	4.66 ± 0.75 Aa	4.85 ± 0.93 Aa	6.94 ± 1.60 Aa

Different letters, uppercase in column and lowercase in row, indicate statistically significant differences (P < .05).

Table 7
Mean and standard deviation values of whiteness index variation (ΔWI_D) as a function of the experimental groups and aging periods.

Experimental Groups	Periods		
	252 Hours	504 Hours	756 Hours
Control	- 1.83 ± 1.88 ABa	- 4.79 ± 1.22 ABa	- 4.96 ± 1.82 ABCa
AA-24H	- 0.26 ± 1.08 Aa	- 3.88 ± 2.62 ABb	- 6.13 ± 2.68 ABCb
AA-14D	- 4.45 ± 2.44 ABa	- 7.93 ± 1.77 ABb	- 5.17 ± 4.43 ABCab
αT-24H	- 1.99 ± 2.16 ABa	- 2.46 ± 4.66 Aa	- 0.92 ± 3.62 Aa
αT-14D	- 2.61 ± 2.41 ABa	- 3.79 ± 2.16 ABa	- 4.81 ± 1.94 ABCa
BLE-24H	- 1.81 ± 4.45 ABa	- 5.28 ± 4.97 ABb	- 3.93 ± 3.61 ABCab
BLE-14D	0.42 ± 1.61 Aa	- 4.34 ± 2.63ABb	- 3.37 ± 2.70 ABab
BLE-AA-24H	- 2.20 ± 2.40 ABa	- 4.76 ± 2.37 ABa	- 3.43 ± 3.69 ABCa
BLE-AA-14D	- 2.20 ± 2.72 ABa	- 4.64 ± 3.67 ABa	- 3.92 ± 5.17 ABCa
BLE-αT-24H	- 5.68 ± 3.14 Ba	- 9.93 ± 4.26 Bb	- 10.13 ± 4.22 BCb
BLE-αT-14D	- 4.48 ± 2.56 ABa	- 5.46 ± 2.85 ABa	- 10.54 ± 4.41 Cb

Different letters, uppercase in column and lowercase in row, indicate statistically significant differences ($P < .05$).

(Table 7). Comparing the second and third aging periods, there were no differences for any experimental groups evaluated ($P > .05$), except for the BLE-αT-14D group, for which 504 h promoted higher ΔWI_D values than 756 h ($P = .011$) (Table 7). Fig. 1 demonstrates that all experimental groups, regardless of the aging period, showed higher ΔWI_D values than the perceptibility threshold for whiteness (WPT = 0.72), except the AA-24H and BLE-14D groups for the first aging period (Fig. 1). Furthermore, all experimental groups promoted higher ΔWI_D values than the acceptability threshold (WAT = 2.62) for the second and third aging periods, except for the αT-24H group (Fig. 1).

4. Discussion

The bleaching treatment and antioxidant agents influenced the chromatic coordinates (ΔL^*, Δa^*, and Δb^*) and whiteness changes (ΔWI_D) of the adhesive interface of ceramic laminate veneers; thus, the first null hypothesis was rejected. Analysis of the influence of UV-accelerated artificial aging periods on ΔL^*, Δa^*, Δb^*,and ΔWI_D led to a rejection of the second null hypothesis.

The UV- accelerated artificial aging method enables the physicochemical performance assessment of luting materials used during the luting process and resembles the conditions of the oral cavity. (Strazzi-Sahyon et al., 2020a) This method has been applied to evaluate the color stability of ceramics and dental materials. (Strazzi-Sahyon et al., 2019; Strazzi Sahyon et al., 2018) Chromatic alterations are associated with extrinsic factors, such as ingestion of foods and beverages presenting pigments in their formulations, heat, humidity, smoking, and UV radiation. (Taşın et al., 2022) Furthermore, color changes are related to intrinsic (Chen et al., 2013) aspects such as concentration and type of the components present in the resin matrix and its hydrolytic deterioration, (Strazzi-Sahyon et al., 2020b) and to iatrogenic failures, such as ineffective polymerization of the resin-based materials. (Lee et al., 2022) Understanding color differences based on visual perceptibility and acceptability thresholds is crucial in clinical practice. (Pérez et al., 2019; Pérez Mdel et al., 2016; Vidal et al., 2020) Thus, dental color research should consider data analysis associated with perceptibility and acceptability values.

Color difference equations are widely used to assess color changes after bleaching procedures. However, exclusively assessing the color differences will not provide enough information on alterations in chromatic coordinates. (Vidal et al., 2020) Thus, authors claim that it is not sufficient to compare whiteness data by applying only color difference metrics, suggesting the use of other indexes to assess whiteness, that are particularly designed for dental material and dentistry evaluations. (Pérez et al., 2019; Pérez Mdel et al., 2016; Vidal et al., 2020) The present study used a whiteness index (WI_D) that is based on CIELAB color parameters, presenting a strong correlation with the visual perception of tooth whiteness compared to other whiteness indexes. Thus, the ΔWI_D values of ceramic restorations that underwent bleaching treatment, antioxidant agents, and distinct periods of aging were analyzed using the perceptibility and acceptability whiteness thresholds (WPT and WAT, respectively).

Considering the antioxidant solutions, the ascorbic acid performance after enamel bleaching (BLE-AA-24 and BLE-AA-14D) showed similar ΔL^* and Δb^* values compared to the bleached and no antioxidant-treated tooth surface (BLE-24H and BLE-14D), differently to control group that yielded lower ΔL^* and Δb^* values during UV-aging periods (Tables 4 and 6). The oxygen free radicals released from the oxidation

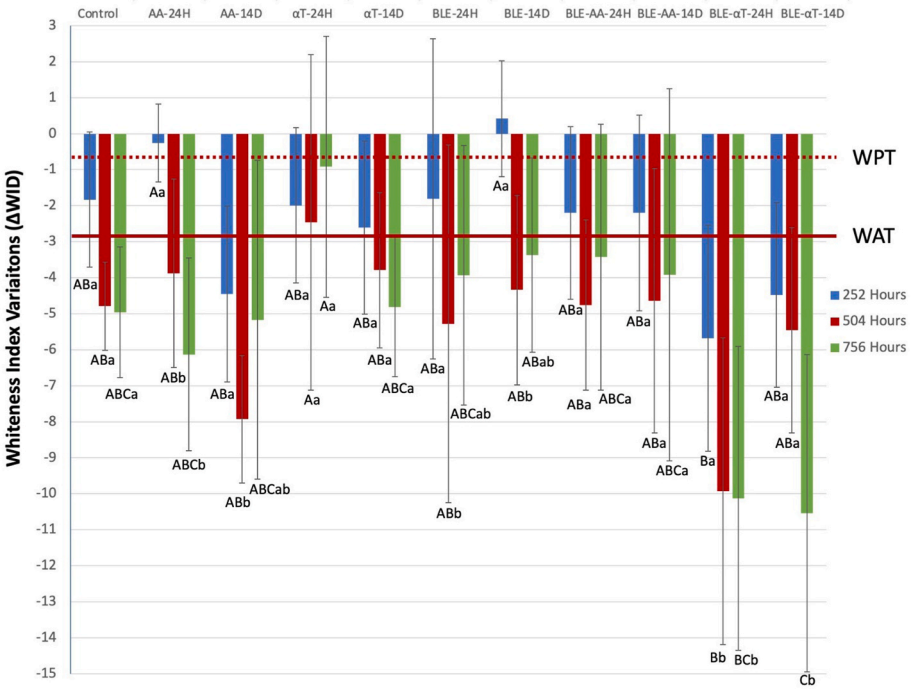

Fig. 1. ΔWI_D values as a function of the experimental groups and aging periods. Dashed line at 0.72 ΔWI_D units and continuous line at 2.62 ΔWI_D units represent the whiteness perceptibility (WPT) and whiteness acceptability (WAT) thresholds, respectively. Negative ΔWI_D values represent that the specimens presented lower WI_D values than the previous evaluation. Different letters, uppercase (comparing the groups to the same experimental condition) and lowercase (comparing the aging periods to the same experimental group), indicate statistically significant differences ($P < .05$).

mechanism of dental bleaching present the capacity to break the organic molecules, converting them to carbon dioxide and water over time. (Sasaki et al., 2009) Naidu et al. claim that the effectiveness of ascorbic acid is equivalent to water and oxygen concentration, and the substrate pH, as ascorbic acid is characterized as a hydrophobic component, presenting high solubility in aqueous media. (Naidu, 2003) Thus, possible neutralization of the antioxidant solution performance can be speculated due to the potential sorption of the water resulting from the bleaching process by the ascorbic acid hydrophilic components, corroborating the higher ΔL^* and Δb^* values (Tables 4 and 6).

In general, the ceramic restoration group luted onto the enamel surface 24 h after the bleaching process (BLE-24H) promoted higher Δa^* and Δb^* values compared to control group during the UV-aging (Tables 5 and 6), becoming the restorations more reddish and yellowish, respectively. According to Freire et al. (2009) the residual hydrogen peroxide and oxygen bubbles accumulated in dental structures hinder the infiltration of the resin monomers into the interprismatic region. (Freire et al., 2009) Furthermore, the bleaching process is able to inhibit the satisfactory polymerization of resin-based materials, as the diffusion of vinyl free radicals during light radiation is hampered by the action of residual free radicals, promoting the formation of premature polymer chain termination. (Freire et al., 2009) A decrease in polymer conversion provides greater degradation of resin matrix, yielding mechanical properties and shear bond strength reduction, poor wear resistance, higher occurrences of fractures and debonding, and higher gap formation and color alteration. (Fróes-Salgado et al., 2010) The uncured monomers can be released from the resinous matrix of the luting agents, leading to porosities that could be filled by water from the condensation stage of the UV-aging, that induces the hydrolysis process of the resin matrix, affecting the optical properties of the restoration assembly. (Strazzi-Sahyon et al., 2019, 2023; Strazzi Sahyon et al., 2018) This could justify the higher Δa^* and Δb^* values of BLE-24H compared to control group during the UV-aging periods (Tables 5 and 6).

Bleached and 10% α-tocopherol-treated enamels luted with ceramic laminate veneers after 24 h and 14 days of the antioxidant action (BLE-αT-24H and BLE-αT-14D) showed similar statistical performance compared to control group along UV-aging periods (Tables 3–7). α-tocopherol is characterized as a hydrophobic component resulting in lower solubility in aqueous media. (Sui et al., 2016) Thus, its performance could be maintained and potentialized due to lower water interaction between the antioxidant agent and the water resulting from bleaching process. (Strazzi-Sahyon et al., 2022)

Some authors have suggested the use of adhesive systems containing organic solvents, such as ethanol and acetone in the formulation, after dental bleaching, as the action of these components on bleached dental surface could decrease the deleterious effects of hydrogen peroxide on resin-based materials adhesion. (Sasaki et al., 2009; Barghi and Godwin, 1994; Kum et al., 2004; Kalili and Yoshida, 1993; Sung et al., 1999) These organic solvents present the capacity to displace the water present in dental structures due to its water chaser properties, allowing the resinous monomer infiltration into the interprismatic region of the tooth substrate. (Nour El-din et al., 2006) The α-tocopherol antioxidant solution used in the current study presents ethanol in its formulation (Table 1). Thus, it can be speculated that the hydrophobicity of the α-tocopherol and the presence of ethanol in the antioxidant formulation may have potentialized the bonding adhesive quality and integrity, confirming the similarity of ΔL^* values of the bleached and 10% α-tocopherol-treated enamel luted with ceramic laminate veneers after 24 h of the antioxidant action (BLE-αT-24H) compared to the control group (Table 4).

In general, there was a tendency to a non-significant difference among the aging periods in chromatic analyses (WI_D, ΔL^*, Δa^*, Δb^*, and ΔWI_D) (Tables 3–7). These data corroborate previous works in which the chromatic alteration was assessed in the first 300 h of aging, after this time, the color change tended to stabilize. Strazzi-Sahyon et al. (Strazzi Sahyon et al., 2018) observed the polymer chain stabilization in the resinous matrix due to the water sorption decrease after 300 h of UV-aged ceramic restorations. (Strazzi Sahyon et al., 2018) This performance may be correlated directly to the luting material composition. Variolink Aesthetic light-cured resin cement presents urethane dimethacrylate (UDMA) as a monomer in its composition (Table 1), which is able to reduce water sorption into the resinous matrix as it is described as a hydrophobic compound. (Strazzi-Sahyon et al., 2019) In relation to Tetric N-Bond Universal adhesive system, the presence of decanediol dimethacrylate (D3MA) and methacrylated carboxylic acid polymers (MCAP) can be noted as monomers (Table 1).

The MCAP is able to react and bond to hydroxyapatite crystals present in dental substrate, and its adhesion is proportional to the concentration of carboxylic acid groups in the polymeric chain. (Cetin and Dinc, 2020) D3MA presents the function of reacting with less polar monomers incorporated into the resin cements, and this component is classified as a hydrophobic monomer, preventing hygroscopy into the resinous matrix. (Cetin and Dinc, 2020) All these characteristics of the adhesive systems promote a strong and well-structured bonding interface. (Strazzi-Sahyon et al., 2022) The Tetric N-Bond Universal adhesive system contains water and ethanol as solvents in its formulation (Table 1), and the water presence would be incorporated by hydrophilic compounds inserted into the resin cement, favoring the hydrolytic deterioration and color alteration of adhesive interface. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) Thus, in the present study the authors photoactivated the adhesive system contained on enamel surface prior to the luting procedure, since previous works adopting this protocol declared a more stable bonding interface regarding color stability and mechanical properties. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) Thus, the progressive temperature increase from light source radiation may have benefited the volatilization of the solvents when the adhesive was previously activated. (Strazzi-Sahyon et al., 2019, 2020a, 2022; Strazzi Sahyon et al., 2018) All these factors could have potentialized the adhesive interface integrity, justifying the non-difference tendency in chromatic changes over the UV-aging periods (Tables 3–7).

After the UV-aging process, in general, WI_D and ΔL^* values decreased, meaning that the specimens became darker, while, generally, Δa^* increased and Δb^* decreased (Tables 3–6). Furthermore, all experimental groups showed negative ΔWI_D values regardless of the UV-aging period, indicating that the specimens showed lower WI_D values in relation to the baseline measurement (Table 7). In general, in all experimental groups, the whiteness variation (ΔWI_D) after UV-aging periods were above perceptibility (WPT = 0.72) and acceptability thresholds (WAT = 2.62) (Fig. 1), which means that all specimens became darker and that this would be perceived by patients. (Vidal et al., 2020)

As related, color changes can be influenced by extrinsic, intrinsic, and iatrogenic factors. (Strazzi-Sahyon et al., 2022) The association of all these factors could corroborate with the negative ΔWI_D values for control, BLE-24H, and BLE-14D groups, in which the unbleached and bleached enamel surfaces did not receive the antioxidant solutions. The UV-aging process could corroborate in these chromatic alterations, as alternate cycles of UV radiation, heat, and moisture may have promoted stress in the resinous matrix. (Strazzi-Sahyon et al., 2019, 2020a; Strazzi Sahyon et al., 2018) In relation to unbleached and bleached groups associated with antioxidant agents, ΔWI_D values could be influenced by the oxidation solution over time, as the effectiveness of the antioxidant agents can be affected by water sorption and temperature oscillation. (Sui et al., 2016) Unbleached and bleached-10% ascorbic acid-treated enamel groups (AA-24H, AA-14D, BLE-AA-24H, and BLE-AA-14D) tended to present similar ΔWI_D values compared to the control, BLE-24H, and BLE-14D groups (Table 7). According to Strazzi-Sahyon et al. (2022) the ascorbic acid effectiveness could be neutralized due to the antioxidant hydrophilic properties, promoting water absorption as a subproduct generated from the bleaching reaction, corroborating the present results (Table 7).

However, the bleached and 10% α-tocopherol-treated enamel groups (BLE- αT-24H and BLE- αT-14D) presented higher negative ΔWI_D values over the UV-aging periods despite a non-statistical difference compared to control group (Table 7). These results could be related to the characteristics of α-tocopherol, such as its hydrophobicity properties. (Strazzi-Sahyon et al., 2022, 2023; Upadhyay and Misra, 2009) Vitamin E is composed of tocotrienol and tocopherol compounds that present α, β, γ, and δ components in its structures. (Doğru Pekiner, 2003; Yamauchi, 1997) α-tocopherol is the most potent of all tocopherols due to its ample performance spectrum, interacting with diverse reactive oxidants. (Doğru Pekiner, 2003; Yamauchi, 1997) Furthermore, its effectiveness and performance are proportional to the free radical concentration. (Doğru Pekiner, 2003) Differently to other kinds of antioxidants, the effectiveness of vitamin E is prolonged by its regeneration from its oxidized products. (Doğru Pekiner, 2003) Thus, α-tocopherol is able to hinder free radicals by proving one of its electrons to the free radical. (Strazzi-Sahyon et al., 2022, 2023) However, different from other types of antioxidant, after the electron donation this antioxidant does not convert into a new free radical, remaining stable over time, providing its regeneration action. (Doğru Pekiner, 2003) The effectiveness performance of α-tocopherol antioxidant was assessed by Strazzi--Sahyon et al. (2022) who claimed that this agent was able to neutralize the hydrogen peroxide from dental bleaching procedure over time. (Strazzi-Sahyon et al., 2022) The potent performance of this agent associated with temperature oscillation from UV-aging could contribute to higher oxidation, promoting higher negative ΔWI_D values (Table 7).

Studies have recommended a delay varying from 7 to 28 days before performing the restorative procedure after dental bleaching to allow the displacement of any residual oxygen from the interprismatic regions. (Freire et al., 2009; Feiz et al., 2017; Bittencourt et al., 2013) In the present study, a delay period of 14 days was assessed. There were no statistical differences in the ΔWI_D analysis between the BLE-14D and control groups (Table 7), thus suggesting that the deleterious reaction of dental bleaching has the tendency to be neutralized after a delay of 14 days. These results can be supported by previous studies carried out by Metz et al. (2007) and Wilson et al. (2009)

Several published studies investigated the use of antioxidant agents after dental bleaching, assuaging the deleterious effects of hydrogen peroxide on the adhesion of composite resins; despite not totally reverting the effects. (Souza-Gabriel et al., 2020; Karadas and Demirbuga, 2019; Harrison et al., 2019) However, studies evaluating the influence of antioxidant agents after dental bleaching for luting ceramic laminate veneers undergoing the aging process are scarce. Few studies have assessed the influence of ascorbic acid and α-tocopherol as antioxidant agents after dental bleaching on nanohardness, elastic modulus, and degree of conversion of the adhesive system and light-curable resin cement in ceramic laminate veneer luting, as well as on shear bond strength, adhesive interface morphology, hydrogen peroxide neutralization, and enamel surface properties undergoing the aging processes. (Strazzi-Sahyon et al., 2022, 2023) Strazzi-Sahyon et al. (2023) observed that a 10% α-tocopherol agent was able to revert the deleterious bleaching effects on mechanical properties of the luting agents present on the bonding interface, suggesting that the use of this solution 24 h after the dental bleaching yield similar data compared to the control group. (Strazzi-Sahyon et al., 2023) Furthermore, the authors also concluded that the use of 10% α-tocopherol completely reverted the adverse effect of bleaching treatment on shear bond strength, yielding satisfactory integrity of the adhesive interface morphology of the ceramic laminate veneer restorations, as this agent used 24 h after dental bleaching also promoted similar performance to the control group. (Strazzi-Sahyon et al., 2022)

Although the use of 10% α-tocopherol 24 h after the bleaching procedure (BLE-αT-24H) promoted higher numerical negative ΔWI_D values (Table 7), it is important to emphasize that this experimental group did not present statistically significant differences in chromatic coordinates change (ΔL^*, Δa^*, and Δb^*) and whiteness variation (ΔWI_D) analyses compared to the control group (Tables 4–7). Regarding the benefits of α-tocopherol as an antioxidant, its satisfactory performance confirmed in previous studies, and the non-statistically significant difference in the present study on ΔL^*, Δa^*, Δb^*, and ΔWI_D analyses, it can be assumed that the use of 10% α-tocopherol as an antioxidant agent immediately after enamel bleaching is a promising and effective approach in the ceramic laminate veneer luting process.

The assessment of only one type and concentration of bleaching product, only one concentration of antioxidant agents, and one adhesive system and resin cement could be classified as limiting factors of the present study. The application of these laboratorial data to a clinical situation should be conducted and interpreted with prudence, as this *in vitro* study did not evaluate the conditions present in a clinical scenario, such as the influence of saliva, enzymes, microorganism, mastication dynamics, tooth brush cleaning action, and presence of other pigments. Further in-depth research and longitudinal clinical investigations must be encouraged to assess the influence of in-office and at-home dental bleaching processes associated with different types of antioxidants under distinct concentrations and times of action on color and whiteness stability of indirect restorations, aimed at improving the luting techniques and clinical durability of ceramic laminate veneers.

5. Conclusion

Based on the methodology and findings of this *in vitro* study, the following conclusions were drawn:

1. Bleaching treatment and antioxidant agents compromise the aesthetic results of ceramic restorations influencing the color coordinates (ΔL^*, Δa^*, and Δb^*) and whiteness stability (ΔWI_D) of the adhesive interface of ceramic laminate veneer luting.
2. UV-accelerated artificial aging influences the ΔL^*, Δa^*, Δb^*, and ΔWI_D color parameters.
3. α-tocopherol is a suitable antioxidant solution to be used 24 h post enamel bleaching considering the perceptibility (WPT) and acceptability (WAT) thresholds.

CRediT authorship contribution statement

Henrico Badaoui Strazzi-Sahyon: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **André Luiz Fraga Briso:** Methodology, Validation, Visualization, Writing – review & editing. **Paulo Henrique dos Santos:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

There are no conflicts of interest to declare.

Data availability

Data will be made available on request.

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