Research Article

Color change, intrapulpal temperature variation, and surface roughness of different bleaching protocols associated with violet LED

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ABSTRACT: Purpose: To evaluate the laboratory color change, intrapulpal temperature variation and enamel surface roughness after tooth bleaching using violet LED light (LED), with or without high concentration bleaching gels. **Methods:** Dental crowns of bovine incisors were submitted to whitening protocols: Control (without treatment), 35% hydrogen peroxide (HP) and 37% carbamide peroxide (CP) associated or not with LED (LED/HP and LED/CP) or only LED. The whitening protocol consisted of three sessions of bleaching gels application for 30 minutes every 7 days or eight sessions with LED protocol. Groups (n= 10) were assessed for color (ΔE_{00}) and whiteness index changes (ΔWI_D), temperature variation (Δ°C) and surface roughness (Ra), prior to the beginning of the whitening treatment, in the last session and 14 days later. Data were analyzed by generalized linear models, Kruskal Wallis, Dunn and Mann Whitney tests (α= 0.05). **Results:** HP and CP, with or without LED, promoted greater color change than LED. LED/CP promoted higher color change than CP. LED significantly increased intrapulpal temperature compared to non-irradiated groups. No protocol promoted a significant increase in surface roughness. (*Am J Dent* 2025;38 Sp Is A:26A-31A).

CLINICAL SIGNIFICANCE: The use of violet LED light could potentiate 37% carbamide peroxide effect; however, light increased the intrapulpal temperature in laboratory conditions.

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Introduction

Whitening gels containing high-concentrate hydrogen peroxide (HP) are the chemical agents mostly used during the in-office technique for vital teeth whitening, with proven efficacy in several studies and clinical observations.[1] Although 35% HP is effective, several light sources (plasma arc, halogen light and diode laser) have been combined with the office technique over the years, aiming to enhance the whitening effect and to reduce the time of clinical care by accelerating the decomposition of HP into reactive oxygen species.[2] In this context, the use of a light source with LED technology in the visible violet wavelength (405-410 nm) has been proposed as an alternative whitening technique, which can be used in combination with high or low concentrations of pH, or without application of peroxides.[3]

Violet LED light (LED) holds a low penetration capacity and is unable to be transmitted in enamel specimens with a thickness higher than 1 mm,[4] a fact that may indicate greater safety in use. In addition, previous studies indicate that LED without combination with any chemical agents promotes color change in artificially pigmented teeth,[3-5] but less effectively than HP or carbamide peroxide (CP).[6] Nevertheless, it was observed that the combination of LED with 37% CP potentiates the whitening effect promoted by CP, to match the effectiveness of 35% HP.[6]

However, the LED application protocol (20 1-minute irradiations) may increase the irradiation temperature, as the 30 seconds interval among irradiations (indicated by the manufacturer to dissipate the thermal energy generated by LED) may be insufficient to the light cooling down process.[4,6] Furthermore, since the enamel morphology is influenced by the rheological and compositional characteristics of bleaching gels and by the oxidative events of hydrogen peroxide,[3] surface roughness analysis becomes necessary to assess the effects of the protocol with LED on bleaching gels' behavior and its consequence in the integrity of the enamel.

Considering the few reports on the use of violet LED light combined with high concentration whitening gels (37% CP and 35% HP) in relation to possible structural and biological consequences, this laboratory study evaluated the effectiveness of these protocols in color changing, its effects in intrapulpal temperature variation and on surface roughness. The studied null hypotheses were that (1) there was no difference in tooth color change promoted by the bleaching protocols tested; (2) there is no increase in intrapulpal temperature in bovine incisors submitted to the bleaching protocols tested; and (3) the bleaching protocols do not increase enamel surface roughness.

Materials and Methods

Specimen preparation - Bovine incisors were extracted, cleaned and stored in 0.1% thymol solution at 4ºC for no longer than 60 days. Sixty teeth without cracks and defects in the enamel were selected. The roots were cut in a low-speed saw (Isomet[a]) under refrigeration 2 mm below the cementoenamel junction and pulp tissue was removed with endodontic files. The root canals were irrigated with saline solution and the thickness of the buccal surface was standardized at 3.5 mm using a thickness gauge to simulate the anatomy of young patients.

The specimens were artificially stained with a solution of black tea[b] (2 g of tea) boiled in 100 ml of distilled water) for 24 hours.[3,7] An aperture of 36 mm^2 (6 × 6 mm) in buccal face was isolated using a nail varnish[c] and the root opening was sealed with utility wax before the blocks were completely immersed in the tea infusion and continuously stirred. After pigmentation, the specimens were stored in distilled water for 1 week, with daily changes.[7]

Table 1. Mean (standard deviation) of ΔE_{00} and ΔWI_D after bleaching protocols.

			Bleaching treatments		
		Light	Without	CP	HP
ΔE1	T_B	Without	3.24 (1.69)Bb	15.39 (4.04) Ab	16.82 (4.32) Aa
		With	13.79 (5.38)Ba	23.54 (5.99) Aa	21.70 (3.66) Aa
ΔE2	T_{14}	Without	4.08 (2.20)Bb	14.52 (4.50) Ab	16.58 (5.15) Aa
		With	13.09 (5.63)Ba	22.12 (5.93) Aa	21.79 (3.67) Aa
ΔWI_D	T_B	Without	-1.18 (8.20)Bb	31.45 (15.00) Ba	39.35 (12.40) Ab
		With	66.68 (14.31)Aa	44.90 (9.65) Aa	58.52 (14.75) Aa
ΔWI_D	T_{14}	Without	-3.81 (9.88) Bb	30.82 (15.66) Ba	37.09 (15.59) Ab
		With	60.99 (13.60) Aa	44.01 (9.63) Aa	59.71 (14.36) Aa

Different letters (uppercase comparing gel groups horizontally and lowercase comparing groups with and without light, vertically) indicate statistically significant differences ($P < 0.05$).

Dental bleaching procedures - The specimens were randomly divided into six groups (n= 10), according to the association of the factors under study:

1. C: Without treatment (control group).
2. HP: 35% hydrogen peroxide.
3. CP: 37% carbamide peroxide.
4. LED/HP: 35% hydrogen peroxide + Violet LED light.
5. LED/CP: 37% carbamide peroxide + Violet LED light.
6. LED: Violet LED light.

Single application of 35% HP (Whiteness HP Maxx[d]) or 37% CP (Whiteness Super Endo[d]) whitening gels were carried out onto the enamel surface during 30 minutes for three sessions at 7-day intervals. While 35% HP and thickener were mixed prior to the application on the specimens, 37% CP was applied directly from its commercial syringe.

Groups submitted to irradiation, with or without gels, were exposed to 20 × 1-minute violet LED light irradiations (Bright Max Whitening[e]) in consecutive 30-second intervals (total irradiation cycle time = 30 minutes). A moist gauze was applied over the surface of the specimens at the intervals (LED group only). A mouth-like shaped template was obtained to simulate the teeth alignment during violet light irradiation for all LED groups. This protocol was repeated for eight sessions at 4-day intervals for the LED group, and for three sessions at 7-day intervals for LED/HP and LED/CP groups.

LED is composed of four light emitting diode lamps (401.82 nm = violet wavelength), with an illumination area of the curved acrylic tip equal to 10.7 cm^2. The unbleached specimens were maintained in artificial saliva (AS) throughout the study, with periodical changes every 2 days (C group).

For carrying out bleaching protocols, the incisal edge of the incisors was fixed with sticky wax on resin plates so that the crown remained in a vertical position and the enamel surface was exposed for treatment and color determination. During bleaching treatment, teeth were placed in a temperature-controlled environment at 37ºC and relative humidity at 50%. Afterward, the specimens were immersed in artificial saliva (1.5 mM Ca, 0.9 mM P, 0.1 M Tris Buffer, pH 7.0; 3.125 ml/mm^2 of exposed enamel) stored in an oven at 37°C for either 4 or 7 days between clinical sessions. The remineralizing solution was renewed every 2 days.[3]

Colorimetric evaluation - Color was determined after staining (T_0), 24 hours after the last bleaching session (T_B) and 14 days after the last session (T_{14}) on the exposed buccal surface of the enamel. Three color readings were performed on the enamel using the digital spectrophotometer (Vita Easy Shade[f]), which recorded the values of CIE L*a*b* coordinates. While L* represents luminosity, a* and b* indicate the measurement of the red*green and yellow*blue axes, respectively. ΔL, Δa and Δb were calculated at both time intervals: 1 (T_B-T_0) and 2 (T_{14}-T_0). Subsequently, the Δ values were individually applied in the formula CIEDE2000 (ΔE_{00}) to obtain ΔE_1 and ΔE_2 for each specimen. The 50:50% perceptibility threshold (PT) for the adopted values was 0.8 ΔE_{00} units.[8,9]

Moreover, Δ values considering the same time points above, were calculated for the whiteness index for dentistry (ΔWI_D), based on the CIELAB system = 0.55L* − 2.32a* − 1.100b*. The 50:50% perceptibility threshold for the whiteness index change (WPT) was considered 0.61 ΔWI_D units.[10]

Intrapulpal temperature evaluation - The interior of the pulp chamber of the assessed incisors was filled with thermal paste (Implastec[g]) to conduct heat. The teeth were placed in an isolated light chamber (GTI Mini Matcher[h]) and the temperature was controlled at 35ºC and relative humidity at 50%.[11] Then, A K-type thermocouple (MT-507[i]) was inserted into the pulp chamber of the bovine incisors through the root canal and kept in contact for 30 minutes with the axial wall of the buccal surface of dentin to determine the intrapulpal temperature.

In groups with LED application, the device was kept 8 mm away from the buccal surface of the bovine incisors (according to the manufacturer's indication) parallel to the central face of the incisors. In the groups with gels, a 1 mm-thick layer of the whitening gel (HP or CP) was applied on the enamel surface. Temperature values were reported at the beginning of bleaching protocol and after 30 minutes. After the measurement time, the thermal paste was removed with an endodontic cannula, the tooth was washed and stored in artificial saliva at 37ºC. Differences between initial and final temperature were determined for all groups.

Surface roughness evaluation - Sixty enamel/dentin specimens (n= 10, 5 × 5 mm) were obtained from bovine incisors, using diamond discs on a precision cutter (Isomet). The area corresponding to dentin was flattened using a polishing machine[j] with silicon carbide papers #600 under water-cooling. The outer enamel surface of each block was finished with aluminum oxide grit #600, 1,200, and 2,000. The blocks were polished using diamond aqueous suspensions (6 µm, 3 µm, 1 µm and 0.25 µm, Metaldi Supreme[a]) and polishing cloths,[a] and ultra-

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Table 2. Mean (standard deviation) of intrapulpal temperature (ºC) as a function of gel, light and time.

Light	Time	Bleaching treatments		
		Without	CP	HP
Without	Baseline	35.00 (0.00) Aa	35.00 (0.00) Ab	35.00 (0.00) Ab
	30 minutes	35.00 (0.00) Ba	35.10 (0.08) Aa	35.18 (0.10) Aa
With	Baseline	35.00 (0.00) Ab	35.00 (0.00) Ab	35.00 (0.00) Ab
	30 minutes	48.60 (2.17) Aa*	49.70 (1.34) Aa*	49.30 (1.25) Aa*

* Differs from the group without light, under the same condition of bleaching treatments and time (P< 0.05). Different letters (uppercase comparing gel groups horizontally and lowercase comparing time, in each light category, vertically) indicate statistically significant differences.

Table 3. Mean (standard deviation) of temperature variation (ΔT, ˚C) at baseline and final evaluation times, as a function of gel and light.

Light	Bleaching treatments		
	Without	CP	HP
Without	0.00 (0.00) Bb	0.10 (0.08) Ab	0.18 (0.10) Ab
With	13.60 (2.17) Aa	14.70 (1.34) Aa	14.30 (1.25) Aa

Different letters (uppercase comparing gel groups horizontally and lowercase comparing groups with and without light, vertically) indicate statistically significant differences (P< 0.05).

Table 4. Mean (standard deviation) of roughness (µm) as a function of gel, light and time.

Light	Time	Bleaching treatments		
		Without	CP	HP
Without	Baseline	0.126 (0.085) Aa	0.099 (0.009) Aa	0.096 (0.008) Aab
	1º Session	0.099 (0.005) Aa	0.098 (0.006) ABa	0.092 (0.004) Bb
	2º Session	0.099 (0.005) Aa	0.098 (0.007) Aa	0.124 (0.095) Aa
	3º Session	0.127 (0.086) Aa	0.098 (0.008) ABa	0.093 (0.005) Bab
	After 14 days	0.100 (0.005) Aa	0.098 (0.008) ABa	0.094 (0.005) Bab
With	Baseline	0.093 (0.007) Aa	0.090 (0.007) Ab	0.094 (0.011) Aa
	1º Session	0.085 (0.006) Bb	0.092 (0.006) Aab	0.096 (0.011) Aa
	2º Session	0.091 (0.004) Bab	0.094 (0.005) ABa	0.098 (0.010) Aa
	3º Session	0.091 (0.004) Aab	0.093 (0.005) Aab	0.097 (0.010) Aa
	After 14 days	0.093 (0.003) Aa	0.093 (0.006) Aab	0.097 (0.011) Aa

*Differs from the group without light, under the same conditions of gel and time (P< 0.05). Different letters (uppercase comparing gel groups horizontally and lowercase comparing time, in each light condition category, vertically) indicate statistically significant differences (P< 0.05).

sonically cleaned in distilled water for 10 minutes.

Surface roughness was determined after the staining protocol, after each whitening session, and after 14 days of storage in artificial saliva using a contact roughness meter (Surfcorder SE1200[k]), calibrated at a 0.25 mm cut-off and 0.2 mm/second speed. Three measurements were performed rotating the specimen 45º, and the mean value for each sample was calculated.

Statistical analysis - Data were analyzed with R software[l] and descriptive and exploratory analyses were performed. Color data were analyzed by non-parametric tests of generalized linear models (factors: bleaching agents, light, and the interaction between them, α= 0.05). The temperature variation (ΔºC) and roughness (Ra) data were analyzed by non-parametric tests, with the Kruskal Wallis and Dunn tests to compare the groups of gels, Mann Whitney to compare the groups with and without light (ΔºC, Ra), Wilcoxon (ΔºC) or Friedman - Nemenyi (Ra) to compare evaluation times (α= 0.05).

Results

Color change and Whiteness Index change - The obtained results for color variation are presented in Table 1. The analysis showed that the factors Gel (P< 0.001) and Light (P< 0.001) significantly influenced both evaluation results, with significant interaction between factors (P< 0.001). After the third session and after 14 days, the variation in color ΔE_{00} and ΔWI_D was significantly greater in the presence of light in the groups without gel and CP. For HP, no significant difference was observed between the groups with and without light. Regardless of the presence of light, CP and HP promoted greater color change than LED. There was no significant difference between carbamide peroxide and hydrogen peroxide in terms of color variation.

Intrapulpal temperature variation - Table 2 displays intrapulpal temperature variation results. No temperature differences were noted for the group without the gel and without light. At the final evaluation time (30 minutes), for groups without light, the temperature was significantly higher when using the gels (CP or HP) in comparison with groups without the gel. In addition, there was no significant difference among light irradiated groups. At 30 minutes, light-irradiated groups exhibited a significantly higher temperature than the groups without light, regardless of the gel.

Temperature variations between baseline and the final evaluation time points are presented in Table 3. For the groups without light, the variation was significantly greater in the presence of gel (CP or HP) than in its absence. In the presence of light, there was no significant difference between the three groups. Thus, the temperature variation was significantly greater in the presence of light than in its absence, regardless of the gel.

Surface roughness - The HP, and LED/CP showed significant variations in roughness over time (Table 4). In the HP group, roughness increased from the first to the second session, but it did not differ significantly between baseline and after 14 days. Regarding the LED, roughness decreased after the first session and significantly increased after 14 days, but the roughness after 14 days did not differ significantly from the baseline.

In the LED/CP, roughness after the second session was significantly higher than at baseline, and after 14 days, roughness also did not differ significantly from baseline. After the first and third sessions and after 14 days, the roughness was lower in the group HP without light than in the group without gel. With light, after the first and second sessions, the roughness was significantly higher with HP than LED. Furthermore, after the first session, roughness was significantly higher in CP than in LED. In the no-gel condition, roughness was always significantly lower in LED. For CP, at baseline, the roughness was significantly lower in the group with light. It is noteworthy mentioning that mean surface roughness values ranged from 0.092 to 0.127 µm for groups without light, and 0.092 to 0.098 µm for groups irradiated with light. Besides, after 14 days, none of the tested protocols increased enamel surface roughness compared to baseline values.

Discussion

The whitening technique using only the violet LED light (LED) was able to promote highly perceptible color and whiteness index changes in the artificially pigmented bovine enamel; however, such effectiveness was significantly lower than the result achieved with the HP and CP agents, regardless of the evaluation time. Similarly, other authors demonstrated that LED promoted whitening of pigmented enamel with black tea, but in a lesser extent than HP or CP.[3,12,13] Thus, this study reinforces that the whitening protocol with LED without the presence of HP or CP does not present the same effectiveness as the oxidizing agents. Therefore, the first null hypothesis that there was no difference in tooth color change promoted by the bleaching protocols tested, was rejected.

Randomized and controlled studies have reported that, although the whitening effect promoted by LED alone is considered perceptible,[6,14] its efficacy and perception are inferior in patients in comparison to the findings of in vitro studies. It is noted that the chromatic alteration is reduced in a clinical situation due to the lower presence of extrinsic pigments in patients prior to bleaching (whether by previous prophylaxis, diet, oral hygiene habits), compared to artificial pigmentation with black tea. Therefore, the evidence reinforces the theory that the mechanism of action of violet light, when used alone, is based on a photocatalytic effect that would favor the action of violet radiation in situations with greater intensity of pigment molecules adhered to the surface of the tooth enamel.[4,5,15] In view of the above, it is suggested that even if the ΔE_{00} and ΔWI_D obtained only with LED are compatible with a noticeable and effective whitening, the same result would not be reproduced in a clinical situation.

However, the evaluation of the combination of LED violet and the 37% CP agent demonstrated a significant increase in the effectiveness (ΔE_{00} and ΔWI_D) for this specific peroxide agent. These findings also corroborate previous laboratory studies,[3,12,16,17] which demonstrated that violet radiation increased the effectiveness of CP at high concentrations and, also, of HP at low concentrations. It is known that only 1/3 of the composition of CP gels consists of hydrogen peroxide. Thus, the CP agent at a concentration of 37% holds a concentration three times lower than HP 35%.[18] The literature suggests that the increase in the effectiveness of bleaching agents with lower concentrations of hydrogen peroxide would be due to the greater dissociation of HP into free radicals, possibly caused by the increase in the temperature of the agent, which, in turn, would lead to a greater occurrence of molecular collisions inside the gels.[3,15]

Currently, it is argued that the greatest benefit of the combination between violet LED and chemical agents in lower concentrations would be the maintenance of the high-quality chromatic results already achieved by HP 35%, together with reduced dental sensitivity.[6,14,19-21] According to the findings of this study, the ΔE_{00} and ΔWI_D values obtained by the LED/CP group were similar to the LED/HP, even after 14 days of storage of dental enamel in artificial saliva. In fact, randomized clinical trials have demonstrated this trend of color changes without significant differences between LED/CP and HP and with an absolute risk of dental sensitivity 30% lower for LED/CP.[6,14] Therefore, the present whitening technique appears as an alternative for patients with dentin hypersensitivity and who, even so, wish to achieve excellent esthetic results in less time than home tooth whitening.

It is important to emphasize that the assessment of intrapulpal temperature in bovine teeth showed a significant increase in the presence of the violet LED, regardless of the combination with CP or HP. Therefore, the second null hypothesis that the bleaching protocols tested with light would not significantly affect the intrapulpal temperature was rejected. Similar ΔT values were found by Qi et al[22] by associating HP 35% to a blue wavelength LED (460 nm). Other laboratory studies[7,23,24] also concluded that the irradiation of peroxide agents with light sources prior to the violet LED promote a significant increase in intrapulpal temperature.

To date, there is little evidence of the effect of LED on tooth temperature during in-office bleaching; however, Klaric et al[25] reported that although other light sources caused a greater increase in intrapulpal temperature than the LED (405 nm), it led to a greater ΔT than the blue LED (400-460 nm). The increase in intrapulpal temperature verified by laboratory studies could justify the occurrence of sensitivity in a randomized clinical trial in 16% of patients submitted to LED treatment without combination with CP or HP gels.[6]

The data from the present study demonstrated that the presence of CP or HP did not significantly interfere with the effect caused by the LED on the mean values of ΔT. Therefore, it is suggested that the insulating effect of peroxide agents on the external surface of dental enamel, already discussed by other authors,[7,12] could be influenced by characteristics of the bleaching agents used, such as the thickness of the applied gel layer, as well as the presence of dyes and viscosity of the whitening agents.

It should be noticed that the ΔT values obtained in the groups with the presence of LED were approximately three times higher than the threshold established by Zach & Cohen[26] for pulpal necrosis events (5.5ºC). However, it must be considered that this study has the limitation of a laboratory design, in which the absence of an intact pulpal blood flow prevents heat dissipation that negatively affects the cell's pulps in a clinical setting.[27] For this reason, future studies could simulate these conditions or even clinically test the effect of violet LED on intrapulpal temperature. Nevertheless, even though these findings have shown T values compatible with possible cell damage, a longitudinal randomized clinical trial

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has already shown that no patient submitted to whitening protocols with violet LED reported a pattern of tooth sensitivity different from volunteers treated without LED, even after 1 year of tooth whitening.[19]

The evaluation of the surface submitted to bleaching protocols with violet LED is also essential to certify the safety of these procedures. Fourteen days after the end of treatments, violet radiation alone showed a significant decrease in surface roughness compared to the control group (without treatment). It is important to note that none of the bleaching protocols, regardless of the presence of violet light, showed a significant change in Ra when evaluated individually and over time. Therefore, the third null hypothesis that the bleaching protocols tested would not increase the surface roughness of dental enamel, was accepted. Others also concluded that protocols with violet LED, with or without peroxide agents, did not interfere with the surface roughness of bovine enamel,[28] and that bleaching with violet LED does not promote changes in surface morphology,[3] mineral content,[5,29] and bond strength of dental enamel.[30]

Contrary to these results, studies[31-33] reported that bleaching agents containing carbamide or hydrogen peroxide result in a significant increase in enamel surface roughness. It is hypothesized that oxidative events triggered by the generation of oxidative oxygen species or even the acidic pH of some peroxide agents generate changes in enamel surface properties.[2] In view of this, the choice of bleaching agents not only with lower concentrations of peroxides, but also with neutral or alkaline pH, can benefit the maintenance of surface roughness after bleaching with violet LED.

This study presents limitations inherent to laboratory studies and the methodologies used. One of these limitations concerns the analysis of intrapulpal temperature variation during the performance of bleaching protocols. Although the environmental conditions of temperature and humidity were controlled and carried out to reproduce previous methodologies,[11] there was no simulation of intrapulpal pressure as in other evaluations carried out for this purpose. Therefore, it is believed that the temperature variations found may be overestimated, as the movement of intrapulpal fluids may influence the sensitivity of the electrode.

In general, the present study suggests that LED bleaching would be favored by combining it with high-concentration CP, achieving excellent levels of color change and whiteness index, as well as preserving the enamel surface. However, whitening only with violet LED does not reach the esthetic levels achieved with peroxides. Although the violet LED increased the intrapulpal temperature to high levels, subsequent studies may test whether this change would occur even in a scenario closer to clinical reality.

Within the limitations of this laboratory study, it can be concluded that (1) the whitening protocol with violet LED alone did not have the same effectiveness in changing the color as HP and CP with or without light. Furthermore, the association LED/CP showed greater color change than CP; (2) under laboratory conditions, the use of violet LED light significantly increased pulp temperature with values above 5.5ºC; and (3) surface roughness was not influenced by violet LED light and no protocol promoted a significant increase in roughness.

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