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ORIGINAL ARTICLE

Influence of surfactants on the effectiveness of bleaching gels

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Abstract This study evaluated the influence of surfactants on the effectiveness of 35% hydrogen peroxide (HP) and 10% carbamide peroxide (CP) bleaching gels. One hundred and forty bovine teeth were used, which were stained by immersion in a coffee, red wine, and tobacco mixture for 7 days. At the end of this process, the color measurement at baseline was taken with the Vita Easyshade spectrophotometer. The teeth were divided into seven groups: (a) negative control (NC), (b) positive control for HP (PC-35), (c) HP + Tween 20 (T20-35), (d) HP + laurel sodium sulfate (LSS-35), (e) positive control for CP (PC-10), (f) CP + Tween 20 (T20-10), and (g) CP + laurel sodium sulfate (LSS-10). Group NC was kept in artificial saliva for 21 days. Groups PC-35, T20-35, and LSS 35 received three applications of bleaching gel for 10 min; the process was repeated after 7 days. Groups PC-10, T20-10, and LSS-10 received the gel for 8 h per day for 14 days. After the bleaching process, the final color was measured. The analysis of variance and Tukey tests showed statistically significant differences for the parameters of ΔL, Δb, and ΔE of the HP gels with surfactant and positive control group (PC-35). Within the limits of this in vitro study, the addition of surfactants to HP bleaching gel increased the bleaching effectiveness.

Keywords Surfactants · Bleaching gels · Teeth

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Introduction

There are two basic bleaching treatment modalities. One is the home-bleaching technique, in which the patient uses a tray containing a carbamide peroxide gel, at low concentrations, for an average period of 2 to 3 weeks. Since it was proposed by Haywood and Heymann [1], in 1989, this technique has become increasingly popular. Nevertheless, the time required to achieve the desired results and the fact of depending on the patient's compliance has resulted in a constantly growing demand for treatment performed in-office. For in-office whitening, the dentist uses a 35% hydrogen-peroxide-based gel, which is applied to the teeth for a period of 30 to 60 min. Although this technique is older than the home-bleaching technique, it was not frequently used for many years, due to its inherent difficulties, such as the use of hydrogen peroxide solution, which was difficult to apply and required absolute isolation. Nevertheless, with improvement in the formulation of bleaching gels, the use of light cured gingival barriers and new sources of energy, the use of in-office bleaching has become more widely disseminated. Among the advantages of in-office bleaching, it does not require the patient's intervention during treatment, and the results can be seen immediately [2].

Irrespective of the technique used, the bleaching agent will, directly or indirectly, be hydrogen peroxide. The current bleaching mechanism is based on the ability of hydrogen peroxide to penetrate tooth structure and produce free radicals that oxidize organic stains within the tooth [3]

Nevertheless, for bleaching gel to act on enamel and dentin, it is necessary for it to diffuse through the dental tissues [4]. It is known that the greater the surface tension of a liquid, the less its ability to diffuse through a surface or to wet it [5]. Surface tension is the force existent between

the surface molecules of a liquid and depends on the values of cohesive and adhesive forces [6]. Some substances are capable of diminishing the surface tension when added to liquids. Surfactants are examples of substances with this property. Surfactant is a word derived from the contraction of the expression "surface active agent", a term that literally means an agent with surface activity. In other words, a surfactant is a compound characterized by the capacity to alter the surface and interfacial properties of a liquid phase [5]. The use of surfactant agents in dentistry has been extensively studied in endodontics [5, 6] in which the addition of these substances to medications and irrigant solutions has facilitated their penetration into root dentin. Greenwall [7] reported that the addition of surfactant to hydrogen peroxide could help it to diffuse to a greater extent through the gel–tooth interface. Therefore, the addition of surfactants to bleaching gel could increase its power of penetration into dental tissues and increase its efficacy.

The aim of this study was to evaluate the influence of the addition of different types of surfactants on the effectiveness of 35% hydrogen-peroxide- and 10% carbamide-peroxide-based bleaching gels, during the bleaching process, by means of the difference in color of the dental elements.

The null hypotheses tested were as follows:

- Storing the teeth in artificial saliva for 21 days would not alter the color of the teeth.
- The addition of surfactants to hydrogen peroxide bleaching gels would not result in significantly greater bleaching than that of the control group.
- The addition of surfactants to carbamide peroxide bleaching gels would not result in significantly greater bleaching than that of the control group.

Material and method

This study was approved by the Research Ethics Committee of the São Jose dos Campos Dentistry School–UNESP (#06/2008). One hundred and forty extracted bovine teeth were used, which had their crowns sectioned horizontally at the height of 11 mm in the incisal direction of the cement enamel junction (CEJ) and 3 mm in the apical direction of the CEJ, in order to remove the root portion. Afterwards they were sectioned in the incisal–apical direction, in order to separate the buccal from the lingual surface and expose dentin. The dentin exposition was done to facilitate the stain penetration. The lingual halves were discarded.

In order to have better visualization and obtain quantification of the bleaching, the teeth were submitted to a stain process. This procedure was sufficient for the teeth to attain a color close to Shade C4, according to the Vita Classical Scale (Vita Zahnfabrik, Bad Säckingen Germany).

Before the stain process, the internal portion of the teeth, corresponding to the exposed dentin was etched with 37% phosphoric acid gel (FGM, Joinville, SC, Brazil), for 30 s, followed by washing with air/water spray for 30 s. The teeth were stained by immersion in a mixture of 250 ml of instant coffee at 25% (Nescafé Original, Nestlé, Araras, SP, Brazil), 250 ml of red wine (Salton, Bento Gonçalves, RS, Brazil), and 50 g chopped tobacco (*Nicotiana tabacum*). A pilot study determined the mixture used in this research. The teeth immersed in the solution were kept in a bacteriological oven ECB 11 Digital (Odontobrás, Ribeirão Preto, SP, Brazil) at 37°C for 7 days.

After this the enamel surfaces were polished with diamond polishing paste with diamonds particles of 2 and 4 μm (Diamond Excel, FGM, Joinville, SC, Brazil) associated with wet felt disks (FGM, Joinville, SC, Brazil) for 30 s.

With the purpose of delimiting the color reading area, a circular adhesive label 9 mm in diameter (Pimaco, Rio de Janeiro, RJ, Brazil) was adhered to the center of the buccal surface. After this, the entire buccal and other surfaces were coated with colorless nail varnish (Colorama, São Paulo, SP, Brazil). After the nail varnish was dried, the label was removed, exposing a dental enamel "window" 9 mm in diameter. The other purpose of impermeabilization was to prevent the artificial saliva and bleaching gels from penetrating into the dentinal tubules during the storage and bleaching periods to which the teeth were submitted and interfering the color.

After staining process, baseline L^* values of each tooth were assessed under standardized ambient conditions according to the CIE-Lab* system using a dental spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany). Mean L^* value of each tooth was used for stratified allocation among seven groups, 20 specimens in each group. It recorded three measurement for each specimen and obtained an average of them. For each measurement, the values of L^*, a^*, and b^* were recorded. The color readings were taken after first (M1) and second (M2) bleaching sessions with 35% HP and after 7 (M1) and 14 (M2) days bleaching with 10% CP. Before each color reading after bleaching procedures, the specimens were kept in artificial saliva for 30 min in order to re-hydrate them [8]. Also the color of the specimens was measured 1 week after the end of the treatment, to evaluate the color relapse.

The specimens were kept in a bacteriological oven at 37°C and in artificial saliva (Byofórmula, São José dos Campos, SP, Brazil) contained $CaCl_2$, $NaC_6H_5CO_2$, $MgCl_2$, NaCl, $C_6H_{14}O_6$, KH_2PO_4, and KCl, during all the time that they were not treated with bleaching agents. The artificial saliva had a neutral pH (7), and was changed every 7 days.

Figure 1 describes the overall experiment design. In groups PC-35, T20-35, and LSS-35, the bleaching gel Total Bleach (Clean Line, Taubaté, SP, Brazil) was used, modified by the manufacturer, by the addition of the surfactants. In the groups submitted to bleaching with 10% carbamide peroxide, the product used was manipulated and basically contained 10% carbamide peroxide, the thickening agent Carbopol, pH regulator, and deionized water, in addition to the surfactants used. The surfactants were added in 5% by weight proportion of the bleaching gels. The following surfactants were used: Tween 20 (Polysorbate 20; Synth, Diadema, SP, Brazil), a nonionic surfactant, and laurel sodium sulfate (sodium dodecyl sulfate; Synth, Diadema, SP, Brazil), an anionic surfactant.

From the color measurement at baseline and those after the bleaching procedures, the values of the changes of L^* (ΔL), of a^* (Δa), and of b^* (Δb) were calculated.

Next, the total change color or the variation in perception of color of each tooth was calculated, designated by the abbreviation ΔE. This parameter was calculated according to the following formula [9]:

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2}$$

The data obtained was analyzed statistically using The Software Statistica for Windows (Statsoft, Tulsa, OK, USA). The tests used were analysis of variance repeated measures and Tukey test at a significant level 0.05.

Results

No statistically significant differences were observed among the color measurements in NC group ($p=0.76$ for L^*, $p=0.17$ for a^*, and $p=0.50$ for b^*). Thus, storing the teeth in artificial saliva promoted no significant alteration in color during the course of 21 days.

Figure 2 presents the color changes (ΔE) in all groups.

For the total color change (ΔE), the statistical analysis revealed significant differences ($p<0.05$) among PC-35 and T20-35 and LSS-35. Nevertheless, no differences were observed among T20-35 and LSS-35. The carbamide peroxide groups showed no significant differences among the experimental groups. After the first measurement, small values of ΔE were observed for the 35% HP groups, while in the 10% CP groups, since after the first measurement (M1), it was observed that ΔE values were above 10. In the groups T20-35 and LSS-35, after second bleaching session, ΔE values revealed no significant differences for the 10% CP groups.

For the gels without surfactant, bleaching with 35% hydrogen peroxide resulted in significantly less color change than when the home bleaching was used. With the addition of Tween 20 or laurel sodium sulfate, two sessions performed with the 35% gel showed no significant differences in comparison with 14 days of bleaching with 10% carbamide peroxide.

Figures 3 and 4 show ΔL and Δb, for all experimental conditions.

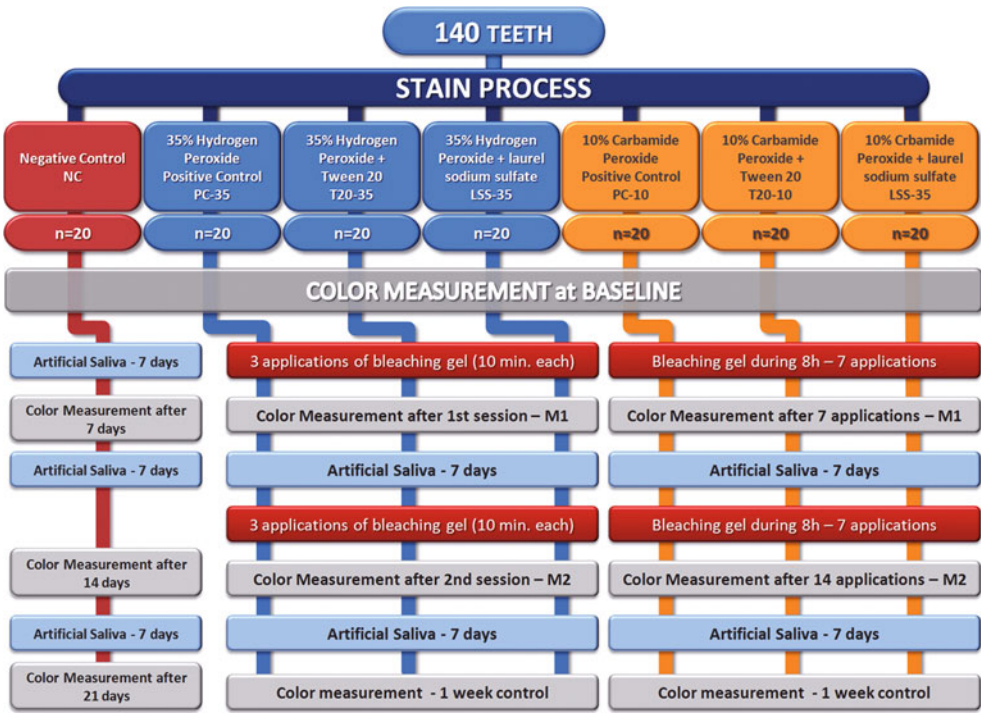

Fig. 1 Experimental study design

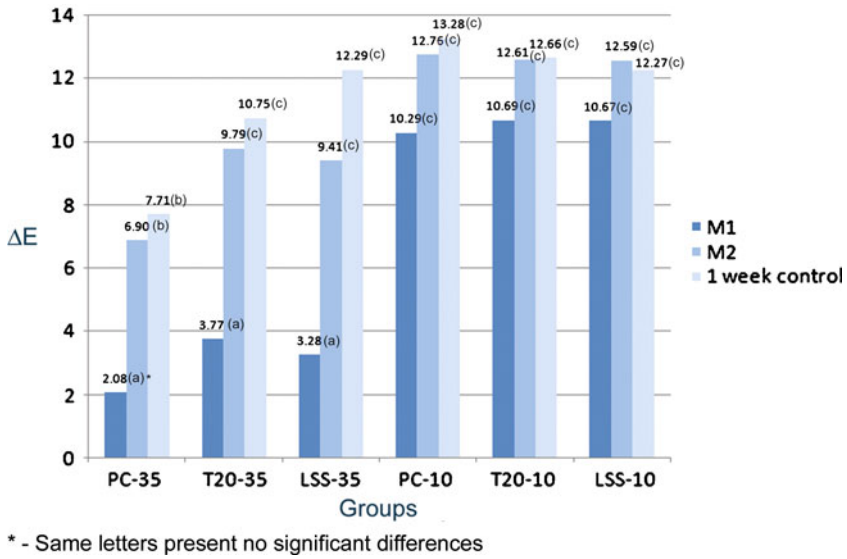

Fig. 2 ΔE values (mean) of all experimental groups

The values of Δ*L* were positive in all measurements as well as in all groups. Therefore, the values of *L** increased during the course of the experiment. As regards *b** values, it was observed negative values of Δ*b*. The *b** values diminished during the course of the experiment, showing that was a diminished of teeth yellowness.

Discussion

The use of bovine teeth allowed the preparation of samples having a standardized size, which is compatible to the dimension of the spectrophotometer. Wiegand et al. [10] also utilized bovine teeth in their studies of bleaching. Kwon et al. [11] found a difference in absolute surface reflectance in human and bovine teeth which could be explained by differences in human and bovine diet and age. Nevertheless, chemical and physical properties such as composition, density, diameter of enamel, heat capacity, and Vicker's hardness are very similar to human enamel [12].

It is necessary to stain the teeth before the bleaching process, particularly with bovine teeth, in order to incorporate pigments into the dental structure and thus allow a greater discriminative comparison of the different bleaching methods and products [13]. In this study, we opted to use a mixture of various substances that can cause tooth staining (coffee, red wine, and tobacco), to allow more than one type of pigment to penetrate into the teeth. In the literature, we found some experimental models for dental pigmentation. Some authors used blood as pigment [13, 14]. In these studies, a situation of staining due to pulp hemorrhage was simulated. This model can be used in internal bleaching studies. Other studies [15, 17] used tea as staining agent.

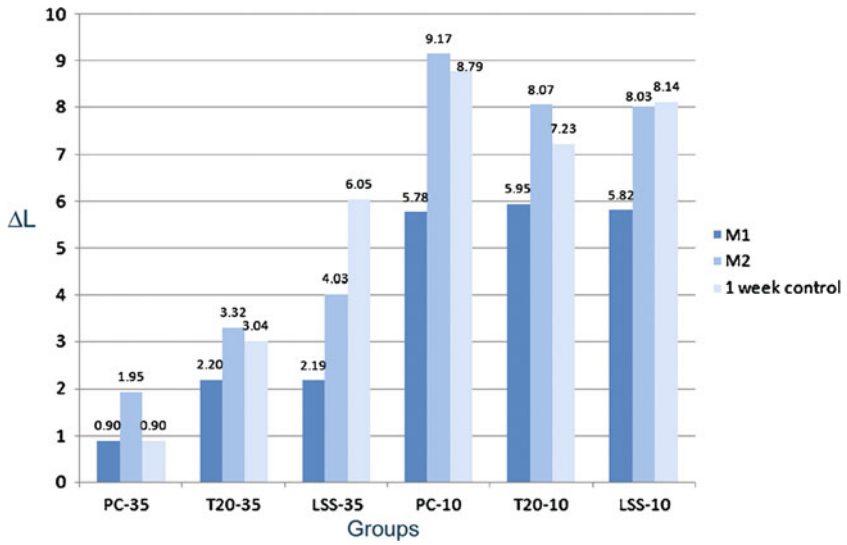

Fig. 3 ΔL values (mean) of all experimental groups

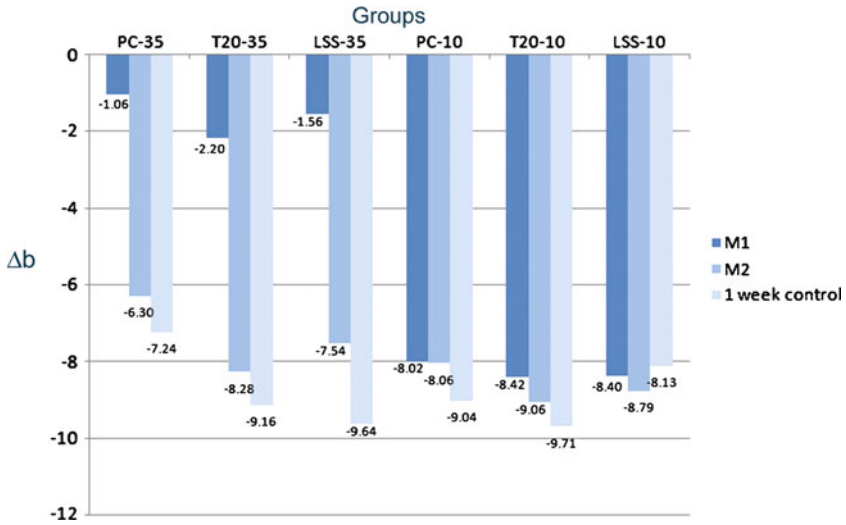

Fig. 4 Δb values (mean) of all experimental groups

Kielbassa et al. [18] stained the teeth in a mixture (1:1) of red wine and black tea for 7.5 days. The authors emphasized that the teeth had been stained artificially to allow comparisons among the different bleaching procedures. Furthermore, Lee et al. [19] proposed a staining model using an artificial coloring, Orange II.

The staining process promoted extrinsic staining on the enamel surface and also intrinsic staining, inside the enamel and dentin. The extrinsic staining was removed by prophylaxis with sodium bicarbonate and polishing the surfaces with felt disks and diamond paste. To ensure that the teeth did not undergo color alterations during the course of the 21 days of the experiment, the negative control group was performed. The teeth remained immersed in artificial saliva for 21 days, and were only removed for color measurement. The results showed that the color coordinates L^*, a^*, and b^* underwent no significant alterations during the 21 days, thus proving the reliability of the methodology used.

This project evaluated the effectiveness of dental bleaching by measuring the color change of the specimens. For this measurement, we used the spectrophotometer Vita EasyShade. This instrument provide data obtained over the range of visible wavelengths (about 400 to 700 nm), captures the tristimuli XYZ and subsequently, calculates the values of L^*, a^*, and b^*.

The great advantage regarding the use of colorimeters or spectrophotometers is the objectivity of the measurement. Horn et al. [20] verified that human evaluation of tooth color was not reliable and that the spectrophotometer could prove to be a more predictable and refined method for evaluating the color of the tooth in vitro, when they conducted a study in which they compared the evaluation of tooth color using a spectrophotometer and human visual analysis. Derdilopoulou et al. [21] evaluated the performance of visual and spectrophotometric tooth shade analysis. The authors found that visual assessment resulted in significantly darker ratings than spectrophotometry and spectrophotometric shade determination seems to be significantly more reproducible than the visual procedure.

The spectrophotometer used provided measurements of the teeth color in the values of the coordinates L^*, a^*, and b^* according to the CIE L*a*b* color model [9]. From these values, it was possible to calculate ΔL, Δa, and Δb, that is, the difference between the readings and also ΔE, which it the total difference in color. There is an intense discussion in the studies of color evaluation in dental bleaching, about which coordinate best shows the bleaching. Li [22] also relates that the most critical challenge in color evaluation with spectrophotometers and colorimeters is the lack of methods for interpreting the data of appliances in relation to the changes in color in studies that evaluate the efficacy of bleaching systems. Bengel [23] observed that after bleaching, the greatest changes occur in the values of the coordinates L^* and b^*, and that the coordinate b^* is the most relevant one for evaluating bleaching treatment. According to the same author, the values of ΔE do not express the total change in color. It is more appropriate evaluate ΔE together the values of L^*. If L^* increased after the bleaching procedure means the teeth tend towards white, as well as a reduction in the values of b^*, with the teeth tending to be less yellow.

For Dietischi et al. [13], when the three color coordinates are analyzed separately, the values of L^*, which represent the luminosity of the samples, appears to be the most significant parameter, while the value of a^* and b^*, which represent saturation, are less useful for making comparisons among products or experimental conditions. Lenhard [24] observed little alteration in the values of the coordinate a^*, an alteration in the values of b^* in the direction of blue, and also an increase in luminosity, with the increase in L^*. Other studies [25, 26] also found a significant improvement

in yellowing (Δb) and luminosity (ΔL) after the bleaching procedure. Luo et al. [27] compared of the ability of different color indices to assess changes in tooth whiteness and concluded that WIO Index was the more appropriate index for evaluating bleaching. The authors also related that of the color coordinates L^*, a^*, and b^*, separately, the coordinate b^* is the most important for evaluating dental bleaching.

With regard to the conditions of use of bleaching agents, the regimens used have been consolidated in the literature. In bleaching with 35% hydrogen peroxide we performed three applications of the products for 10 min, for each session. This regimen was also proposed by Gallagher et al. [28], Zekonis et al. [29], and Sulieman et al. [16, 17]. In our study, no hydrogen peroxide gel activation with any light source was used.

Regarding carbamide peroxide, we used the period of 8 h a day, first proposed by Haywood and Heymann [1] and also used by other authors [29, 30]. Use for 2 weeks is also proposed in various studies [31–33].

With regard to the use of surfactants associated with bleaching agents, there are few studies. Feinman et al. [34], in a literature review on dental bleaching, mentioned that the bleaching agents could contain surfactants, with the object of increasing gel diffusion to inside the tooth. However, they did not elucidate which surfactant could be used and also indicated no result of the experiment about this. Hayman et al. [35], when publishing a patent about the compositions of bleaching agents, mentioned the possibility of the use of surfactants with the object of increasing the wetting capacity of the agents. The authors suggested the use of anionic surfactants, such as laurel sodium sulfate, nonionic surfactants, such as those known as "Tween" as well as amphoteric surfactants. However, they did not indicate the concentration of the substances that should be used.

Observing the results of the tests performed with the 35% HP gel (Fig. 3), we verified positive values of ΔL in all the groups. Thus, there was an increase in the values of L^* over the course of the experiment. As the scale of the coordinate L^* goes from 0 (black) to 100 (white), the teeth underwent an increase in luminosity. When the Tukey test was applied, we observed significant differences between the control group (gel without surfactant) and the groups with surfactant. This result showed that the use of surfactants was efficacious, irrespective of the type, as there were not statistical differences between them.

Regarding the color coordinate b^*, the results were coherent with those found for the coordinate L^*. From this coordinate, we observed that the teeth bleached, by the decrease in the values of b^*, thus presenting negative values of Δb (Fig. 4). For this coordinate, the groups T20-35 and LSS-35 presented significantly higher values of Δb than those of group CP-35, showing that there was a greater reduction in the yellowing of teeth in the group in which the surfactant had been added.

About ΔE (Fig. 2), the total difference in color, the results confirm the results of coordinates L^* and b^*, showing significantly greater changes in color of the teeth in groups T20-35 and LSS-35. By the positive values of ΔL and negative values of Δb, we could tell the direction of the total change in color (ΔE) was in the direction of a lighter color in all the groups, but with a greater difference in comparison with the initial situation in groups T20-35 and LSS-35.

Vieira et al. [36], when studying the transmittance of enamel fragments before and after bleaching, observed a reduction in the transmittance of enamel after bleaching, that is, the enamel became more opaque. Therefore, according to the authors, after bleaching the color of the tooth is less influenced by the subjacent dentin. McCaslin et al. [37] measured the color of dentin after bleaching through the enamel, and observed an increase in the lightness of the dentin, proving that the dentin is also bleached. Wiegand et al. [38] and Sulieman et al. [17], by means of different methodologies, also proved that the bleaching agent acts on both the enamel and dentin. However, Dietschi et al. [13] observed that the in-office bleaching techniques were less efficient than home bleaching for removing pigments deposited in dentin. As previously mentioned, the surfactant acts in a manner to reduce the surface tension and thus allows greater penetration of the bleaching agents. The bleaching agent probably penetrated in greater depth, promoting more extensive bleaching of the enamel and dentin. Nevertheless, as we measured the color on the enamel surface, it is not possible to say whether the hydrogen peroxide associated with the surfactant promoted more extensive bleaching of dentin, when compared with the gel without surfactant.

Regarding 35% hydrogen peroxide, although the bleaching agent had a very high concentration, it remained in contact with the dental tissues for a short time, whereas in home bleaching, the agents remain in contact with the teeth for hours daily. The presence of the surfactant facilitated penetration of the bleaching agent, enabling its greater penetration even in the short time in contact with the teeth.

In groups CP-10, T20-10, and LSS-10 bleaching was performed with 10% carbamide peroxide. Group CP-10 functioned as a control, as the gel did not contain surfactant, and groups T20-10 and LSS-10 contained 5% Tween 20 and 5% laurel sodium sulfate, respectively. When analyzing the results presented in Fig. 3, we observed an increase in the values of L^*, due to positive ΔL and decrease in the values of a^* and b^* due to the negative values of Δa and Δb. This allows us to say that in all the groups the teeth were bleached. For the factor surfactant, no

significant differences were observed in all the color coordinates, as well as for the total difference in color (ΔE; Fig. 2). Therefore, the addition of surfactant in the carbamide peroxide gel did not alter the degree of tooth bleaching. As the bleaching agents remain in contact with the tooth surface for a long time (8 h per day for 14 days) they must have penetrated into the tooth a great deal, not being influenced by the presence of the surfactant. Dahl and Pallesen [39] reported that efficiency of the bleaching procedure depends mainly on the concentration of the agent, its ability to reach the pigment molecules, and the duration and number of times that the agent is in contact with the tooth.

Tredwin et al. [40] reported that various studies on carcinogenesis indicated that hydrogen peroxide could possibly act as a promoter of carcinogenesis. Until further clinical researches are concluded to clarify the question of possible carcinogenicity, the authors recommended that: bleaching products with a high concentration of hydrogen peroxide should not be used without gingival protection; hydrogen-peroxide-based products must be avoided in patients with lesions or diseases in soft tissues; for home bleaching, minimum quantities of hydrogen peroxide (as well as in the form of carbamide peroxide) are preferable; and avoid prolonged exposures and high concentrations. As we found that the surfactant increased the degree of bleaching with 35% hydrogen peroxide, maybe it could be possible to diminish the concentration of the peroxide in a gel with surfactant without losing the effectiveness of the treatment, in addition to making the treatment safer with the reduction of an agent that could be harmful. Thus, further studies could be conducted with the addition of surfactants to dental bleaching agents.

Conclusion

Based on the methodology used and in accordance with the statistical analysis of the results, it was concluded that:

1. The addition of surfactants to hydrogen-peroxide-based bleaching gel resulted in a significantly more extensive bleaching than the use of the gel without surfactant. Thus, the formulated null hypotheses was rejected.
2. The two surfactants used presented no significant differences between them.
3. The addition of surfactants to 10% carbamide-peroxide-based bleaching gel had no influence on the effectiveness of dental bleaching. Thus, the formulated null hypotheses was not rejected.
4. When surfactants were used, two bleaching sessions with 35% hydrogen peroxide provided similar results to those of home bleaching.

Conflicts of interest We have no conflict of interest.

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