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Comparative study of the effectiveness of different bleaching agents on blood-colored extracted teeth and investigation of recoloring after bleaching: an *in vitro* experimental study

Gülşen Arslan[1,*], **Akın Aladağ**[2], **Ayşegül Demirbaş**[1], **Murat Türkün**[1]

[1]Department of Restorative Dentistry, Faculty of Dentistry, Ege University, Bornova, Izmir, Türkiye
[2]Department of Prosthodontics, Faculty of Dentistry, Muğla Sıtkı Koçman University, Mugla, Türkiye

ABSTRACT

Objectives: This study evaluated the efficacy of three distinct bleaching agents over time on blood-stained, devitalized teeth. Furthermore, the recoloring subsequent to bleaching will be monitored.

Methods: The study was conducted on 60 caries-free, unfilled, upper human incisors. The Freccia and Peters blood staining technique was employed, and four groups ($n = 15$) were identified: control, 35% hydrogen peroxide-treated, 37% carbamide peroxide-treated, and sodium perborate-treated groups. Color differences were measured using ΔE_{00}, ΔWI_D, L^*, a^*, and b^* values. To investigate tooth discoloration after bleaching, 10 unbleached teeth with three groups of 10 bleached teeth were compared by vine staining. The group of bleached teeth was restored immediately, another group waited one week, and the third group had sodium ascorbate applied and analyzed using one-way analysis of variance tests ($p < 0.05$).

Results: Among the groups, carbamide peroxide exhibited the most significant whitening during the 6-day bleaching process, followed by hydrogen peroxide and sodium perborate. Subsequent examination of the wine recoloring of post-bleaching samples demonstrated that bleached teeth exhibited a heightened propensity for recoloration in contrast to unbleached teeth. Notably, sodium ascorbate treatments for hydrogen peroxide neutralization and the wait-and-restore approach were not statistically significant in terms of preventing recoloration.

Conclusions: Sodium perborate is less effective and more time-consuming than hydrogen peroxide or carbamide peroxide for bleaching purposes. Carbamide peroxide is the most effective bleaching agent. The sodium ascorbate treatment and the wait-and-restore approach are ineffective in preventing recoloring. Bleached teeth have more discoloration than unbleached teeth.

Keywords: Carbamide peroxide; Hydrogen peroxide; Sodium perborate; Tooth bleaching; Tooth discoloration; Tooth staining

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***Correspondence to**
Gülşen Arslan, DDS
Department of Restorative Dentistry, Faculty of Dentistry, Ege University, Erzene Mah. Ankara Cad. No: 172/109 Bornova, Izmir 35040, Türkiye
Email: dtgulsenarslan@gmail.com

INTRODUCTION

The advent of social media has served to accentuate the societal value and popularity of a beautiful smile and a healthy mouth [1]. More people are getting dental treatments for cosmetic reasons. The prevailing expectation among these patients pertains to the whiteness of the teeth rather than to the alignment, symmetry, shape, and proportionate appearance of the teeth, which are complementary to an aesthetic smile [2].

Color perception can vary from person to person. A multitude of factors, including skin, hair, and gum color, age, and sex, have been identified as potential contributors to variations in tooth color perception. Consequently, patient expectations regarding the whiteness of their teeth exhibit significant variability. In order to address this discrepancy in perception, the ideal tooth whiteness can be defined as a whiteness proportional to the individual's sclera [3,4].

The color of teeth depends on dentin tissue and enamel thickness/texture, which can change over time due to internal/external factors. Frequent consumption of chromogenic foods and beverages such as tea, coffee, cigarettes, and alcohol is known as an external factor. Internal discoloration may be local or systemic. Local causes include pulp necrosis, intrapulpal bleeding, pulp tissue residues following endodontic treatment, endodontic materials, coronal filling materials, root resorption, and aging. Systemic factors encompass metabolic disorders, fluorosis, genetic causes, and drug-induced staining [5]. Although discoloration resulting from different etiologies may necessitate disparate treatment strategies, diffuse discoloration of the entire dental arch can be addressed through micro-abrasion, office bleaching, home bleaching, or over-the-counter products [6]. Discoloration affecting a single tooth or multiple teeth in the smile line can also be treated with intra-coronal bleaching methods [7].

Bleaching treatments have historically utilized a wide range of materials and methodologies. Traditionally, agents such as oxalic acid, chlorine compounds, sodium peroxide, and sodium hypochlorite were employed; however, their efficacy in oxidizing chromogens has been deemed insufficient, coupled with concerns regarding their potential adverse effects on dental tissues [8]. Contemporary research has established that the most effective bleaching results are achieved with hydrogen peroxide (HP) concentrations between 5% and 35%. As a powerful oxidizing agent, HP is widely used across various sectors, including cosmetics, textiles, healthcare, and industry, facilitating tooth whitening through the oxidation of chromogenic compounds [9].

While current bleaching methods are regarded as safe, effective, and minimally invasive, potential adverse effects warrant consideration. Specifically, 30% HP is recognized as corrosive to both skin and ocular tissue.

Additionally, excessive application may harm the gums by penetrating the dentinal tubules, leading to increased sensitivity and potential root resorption [10,11]. In response to these concerns, sodium perborate (SP) and carbamide peroxide (CP) have emerged as preferred alternatives within dental bleaching practices [12].

A substantial body of research has established that the combination of SP and distilled water is effective for bleaching devitalized teeth while concurrently minimizing damage to periapical tissues. Upon reacting with water, SP decomposes to produce sodium metaborate and HP. The lower incidence of adverse effects associated with the SP-distilled water mixture, compared to the conventional HP gel, can be attributed to the higher pH characteristic of this reaction [13].

CP, typically available in concentrations ranging from 10% to 20%, is a widely utilized component in bleaching treatments. Upon reaction, CP undergoes a decomposition process that yields urea, ammonia, carbon dioxide, and HP. Specifically, 10% CP contains approximately 3.3% to 3.5% HP and 6.5% urea [14]. The presence of urea contributes to an alkaline environment conducive to the bleaching process. Carbopol is commonly employed as a carrier in CP gels, enhancing their stability and application. Furthermore, the incorporation of potassium nitrate and fluoride has been shown to mitigate dentin sensitivity, thereby improving the safety profile of CP gels in comparison to HP gels [15]. While both CP and SP gels present unique advantages and disadvantages, it is the HP in these formulations that facilitates the bleaching effect.

HP is recognized for its ability to oxidize discolored tissue and facilitate its removal from the tooth, accom-

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panied by a foaming effect. *In vitro* studies have also been conducted to assess the potential for HP to cause damage to dental tissues [16]. Research utilizing scanning electron microscopy has revealed the formation of microporosities, pits, and areas of erosion resulting from mineral loss, which correlate with the concentration of HP employed [17,18]. As the concentration of HP increases, significant demineralization of the tooth surface occurs, leading to the dissolution of the organic matrix and a reduction in calcium content [19].

The free oxygen radicals generated as by-products of the HP reaction possess unpaired, highly reactive electrons, which have been shown to interfere with the bonding process of dental resins [20]. Inadequate bonding following the bleaching procedure may negatively impact the aesthetic quality of restorations, complicating the subsequent recoloring of teeth [21]. The neutralization of these reactive free radicals is facilitated by saliva, with this process typically requiring an average duration of one week (ranging from 24 hours to 3 weeks). This time frame is conducive to the recoloring of affected teeth. Consequently, many dental practitioners recommend a "white diet" to their patients during this period [22]. Moreover, the use of products such as hydroxyapatite, fluoride, casein phosphopeptide, and antioxidant gels is common in dental clinics to neutralize the effects of bleaching agents and mitigate any post-bleaching complications [23,24].

In light of the existing literature, it can be asserted that the efficacy of bleaching treatments can be assessed based on their capability to alter tooth color, the extent of damage to adjacent tissues, and their effectiveness in preventing the recurrence of discoloration.

The primary objective of this study was to evaluate the efficacy of three different bleaching agents over time, both individually and in comparison to one another. A secondary objective was to examine the degree of discoloration present in bleached teeth. The null hypotheses for this study were articulated as follows:

(i) The bleaching agents under investigation do not differ from one another in terms of bleaching speed and overall effect.

(ii) No significant difference exists between bleached and unbleached teeth concerning post-bleaching recoloring.

(iii) The application of sodium ascorbate treatments for the neutralization of HP, along with the wait-and-restore approach method, did not demonstrate effectiveness in preventing recoloration of bleached teeth.

METHODS

This study received approval from the Research Ethics Committee of the Faculty of Medicine, Ege University located in Izmir, Turkiye (protocol: 21-3T/52). The sample compsed 60 non-carious human incisors extracted for periodontal reasons, obtained from the Oral Surgery Polyclinic of Faculty of Dentistry, Ege University. All selected teeth were caries-free, unfilled upper anterior incisors, devoid of surface abnormalities. Prior to the initiation of the study, the samples were meticulously cleansed of any debris using a soft-bristled brush and subsequently disinfected by immersion in a 10% formalin solution for 48 hours.

Following disinfection, endodontic access cavities were created, preserving 2 mm of hard tissue in the buccal wall. All root canals were shaped, disinfected, and filled by a single research dentist using a standardized method. Canal fillings were subsequently retracted 2 mm from the cementoenamel junction, and the apical area was sealed with glass ionomer cement (3M, Saint Paul, MN, USA). The samples were then placed in moist sponges and stored in an incubator maintained at 37°C with 100% humidity for a duration of 7 days. The initial color of the teeth was assessed using a dental spectrophotometer and the VITA scale (SpectroShade, MHT Optic Research AG, Zürich, Switzerland).

The staining of samples was performed according to the protocol established by Freccia and Peters [25]. The human blood used in this study was sourced from waste blood designated for destruction at the Biochemistry Laboratory, Faculty of Medicine, Ege University. Prior to the staining procedure, the samples were immersed in a 5.5% sodium hypochlorite solution (Microvem, Samsun, Turkiye) for 24 hours to facilitate the opening of dentinal tubules. Subsequently, the teeth were placed in tubes containing 5 mL of plasma-removed erythrocyte suspension and subjected to two daily centrifugation cycles at 3,400 rpm for 20 minutes. This staining procedure was repeated until the teeth attained a color classi-

fication of A3 or darker on the VITA scale, which took a total of 12 days.

Following the staining procedure, the color of the samples was assessed against a white background using a dental spectrophotometer. The 60 samples were stratified and randomly allocated into four groups, each consisting of 15 samples, to ensure a balanced distribution of color values ranging from A3 to C4 on the VITA scale. The control group did not receive treatment with any bleaching agent. The first group (HP group) was treated with a bleaching gel containing 35% HP (Opalescence Endo, Ultradent Products Inc., South Jordan, UT, USA). The second group (CP group) received a bleaching gel containing 37% CP (Whiteness Super Endo, FGM Produtos Odontológicos, Joinville, Brazil). The third group (SP group) was treated with a SP-superoxol mixture, with the cavity sealed using polytetrafluoroethylene tape (Table 1).

The bleaching materials were refreshed every 2 days, and the color of the teeth was measured using the dental spectrophotometer at consistent times, in the same location, and under comparable daylight conditions each day for a duration of 6 days. Color measurements were conducted three times for each tooth, and the mean value was subsequently recorded.

To evaluate the color change following the bleaching process, the bleached teeth were stratified randomly into three groups, with an equal number of teeth (n = 10) treated with each of the three bleaching materials in each group. The rationale for utilizing stratified randomization lies in the varying free radical ratios of the bleaching agents, aiming to ensure that the return of color remained unaffected by these discrepancies. Group 1 was formed from teeth that had never undergone bleaching. In group 2, composite restorations were applied after soaking the teeth in a 10% sodium ascorbate solution for 1 hour. In group 3, the composite restorations were applied immediately following the bleaching procedure. Group 4 involved leaving the tooth cavities empty, filled only with sterile cotton pellets following the removal of the bleaching agent, for a duration of one week (Table 2).

At the end of this period, restorations were performed. Additionally, the teeth were immersed in red wine for 20 minutes per day over the course of 6 days [26]. The color of the teeth was assessed prior to exposure to the wine and subsequently compared to the color after the wine-tinting process.

The color change between samples was recorded in the CIE $L^*a^*b^*$ (Commission Internationale d'Eclairage $L^*a^*b^*$ color space) color system. The formula CIEDE 2000 ($\Delta E_{00} = (\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + RT (\Delta C'/K_C S_C) (\Delta H'/K_H S_H)^{1/2}$) was utilized to calculate the color change between samples. The present study evaluated the bleaching rate of bleaching agents within and between groups over time and the total color

Table 1. Bleaching products and ingredients used

Group	No. of samples	Product	Ingredient
Control group	15	-	Cotton pellet moistened with distilled water
HP group	15	Opalescence Endo (Ultradent Products Inc., South Jordan, UT, USA)	35% Hydrogen peroxide gel
CP group	15	Whiteness Super Endo (FGM Produtos Odontológicos, Joinville, Brazil)	37% Carbamide peroxide gel
SP group	15	Sodium perborate-superoxol mixture	Mixture prepared with 10 g sodium perborate and 2 mL superoxide

Table 2. Processes applied to groups before recoloring with red wine

Group	No. of samples	Process
Group 1	10	Control group
Group 2	10	Composite restoration was performed after the teeth were kept in 10% sodium ascorbate for 1 hour
Group 3	10	Composite restoration was applied immediately after bleaching
Group 4	10	Composite restoration was performed after the bleaching agent was cleaned and kept in the cavity with sterile cotton pellets for 7 days

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change between groups. To this end, the ΔE_{00}, L^*, a^*, and b^* values were examined to determine the amount of daily bleaching within each group. A threshold ΔE_{00} value of 0.8 was taken as the detectability value and 1.8 as the acceptability value. As a complementary measure, the whiteness index (WI_D) values were calculated according to the CIELAB color system. $WI_D = 0.511L^* - 2.324a^* - 1.100b^*$ formula was employed to assess the level of witness within and between groups. In this study, the WI_D (ΔWI_D) was assessed using the whiteness 50%:50% perceptibility (WPT) and 50%:50% acceptability (WAT) thresholds, determined in previous research at 0.72 and 2.60 ΔWI_D units, respectively [26]. To assess recoloring post-bleaching, the color was measured with the same material and method, and the ΔE_{00}, L^*, a^*, and b^* values obtained were compared between groups.

The minimum sample size was established at 60 teeth, determined using G*Power for the comparison of three different bleaching agents, with an expected effect size of 80% at the $\alpha = 0.05$ significance level. All subsequent calculations were performed using IBM SPSS version 20.0 (IBM Corp, Armonk, NY, USA). The Shapiro-Wilk test was employed to assess the normality of the data distribution. When the normality assumption was satisfied for at least two groups, a one-way analysis of variance was conducted to ascertain whether there were statistically significant differences among the groups. Time-dependent intragroup changes were evaluated using Bonferroni correction, with a significance level set at $p < 0.05$.

RESULTS

In the intergroup evaluations, there was a significant difference between the groups in mean ΔWI_D, ΔE_{00}, L^*, a^*, and b^* values ($p < 0.05$) (Tables 3 and 4, Figures 1–5). The CP group exhibited the most significant whitening during the 6-day bleaching process (32.31 ± 12.62), followed by the HP group (22.86 ± 8.25) and the SP group (11.25 ± 4.40). The SP group demonstrated the least whitening among the groups. The WI_D measurements corroborated the ΔE_{00} values. The CP group exhibited the most substantial ΔWI_D (22.88 ± 9.57), followed by the HP group (20.65 ± 10.63) and SP group (6.98 ± 14.87), in that order. A statistically significant discrepancy was identified among the groups ($p < 0.001$). This outcome led to the rejection of the null hypothesis (i). Subsequent to the completion of the bleaching process, a significant difference was observed in the color returned to the bleached teeth in comparison to the

Table 3. Color change (ΔE_{00}) values of specimens over 6 days in each experimental group

Time point	Control group	HP group	CP group	SP group	*p*-value
CVB	3.42 ± 2.34	4.52 ± 3.16	4.67 ± 3.44	3.29 ± 2.27	0.419
ΔE_{00}_day 1	*	16.22 ± 8.78	24.51 ± 4.28	3.98 ± 2.64	<0.001
ΔE_{00}_day 2	*	16.29 ± 7.47	25.05 ± 4.86	7.28 ± 4.88	<0.001
ΔE_{00}_day 3	*	21.10 ± 7.53	25.88 ± 3.68	8.78 ± 3.86	<0.001
ΔE_{00}_day 4	*	21.99 ± 8.02	26.37 ± 3.57	9.88 ± 4.10	<0.001
ΔE_{00}_day 5	*	20.78 ± 8.04	26.18 ± 3.83	12.43 ± 4.53	<0.001
ΔE_{00}_day 6	*	22.86 ± 8.25	32.31 ± 12.62	11.25 ± 4.40	<0.001

Values are presented as mean ± standard deviation.
CVB, color values before bleaching.
Group definitions are provided in Table 1.
*The control group wasn't exposed to any bleaching agent, so the initial measurement values were considered constant.

Table 4. Whiteness index (WI_D) values before and after bleaching

Time point	Control group	HP group	CP group	SP group	*p*-value
ΔWI_D_day 1	3.67 ± 12.41	−2.90 ± 11.03	4.25 ± 11.75	−3.62 ± 8.07	0.112
ΔWI_D_day 6	3.67±12.41	20.65 ± 10.63	22.88 ± 9.57	6.98 ± 14.87	0.001

Values are presented as mean ± standard deviation.
Group definitions are provided in Table 1.

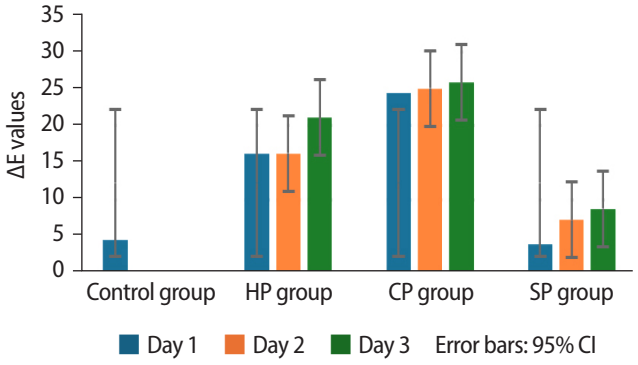

Figure 1. Daily change rates of mean color difference (ΔE) values. Group definitions are provided in Table 1. CI, confidence interval.

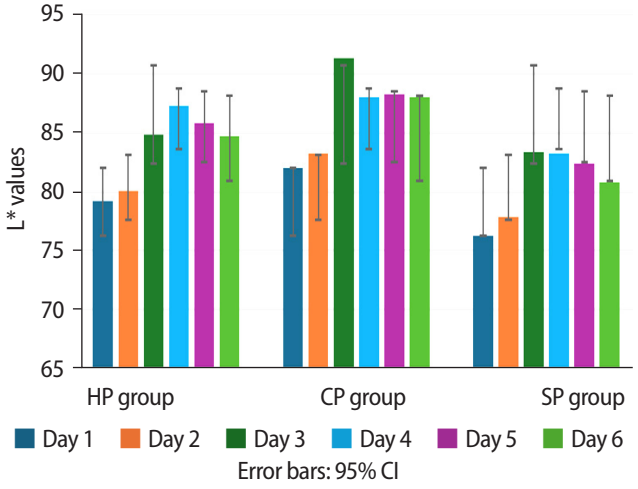

Figure 2. Daily change rates of mean L* values. Group definitions are provided in Table 1. CI, confidence interval.

control group, thereby confirming the rejection of the null hypothesis (ii). However, no significant difference was detected among the bleached teeth in groups 2 to 4, which led to the acceptance of the null hypothesis (iii) (Table 5, Figure 6).

DISCUSSION

The discoloration of the teeth following root canal treatment of the anterior teeth and the search for solutions to the aesthetic problems associated with it have been the subject of many studies. In 1982, Freccia and Peters [25] argued that "How well a bleaching method works depends on the cause of the discoloration." In light of the presented information, the decision was made in our study to utilize blood as the staining agent to simulate hemosiderin staining resulting from posttraumatic hemorrhage and necrotic pulp tissue, which is the most common staining agent [25].

Determining tooth color is a complicated process due to the varying surface structures and colors present on different tooth surfaces. Dental shade guides, which are commonly utilized in clinical settings for colorimetric analysis, are not objective methods due to their reliance on the subjective perceptions of the practitioner, the color of surrounding tissues, and ambient light, among other factors [27]. In our study, we employed a dental spectrophotometer to obtain objective, accurate, and reliable results.

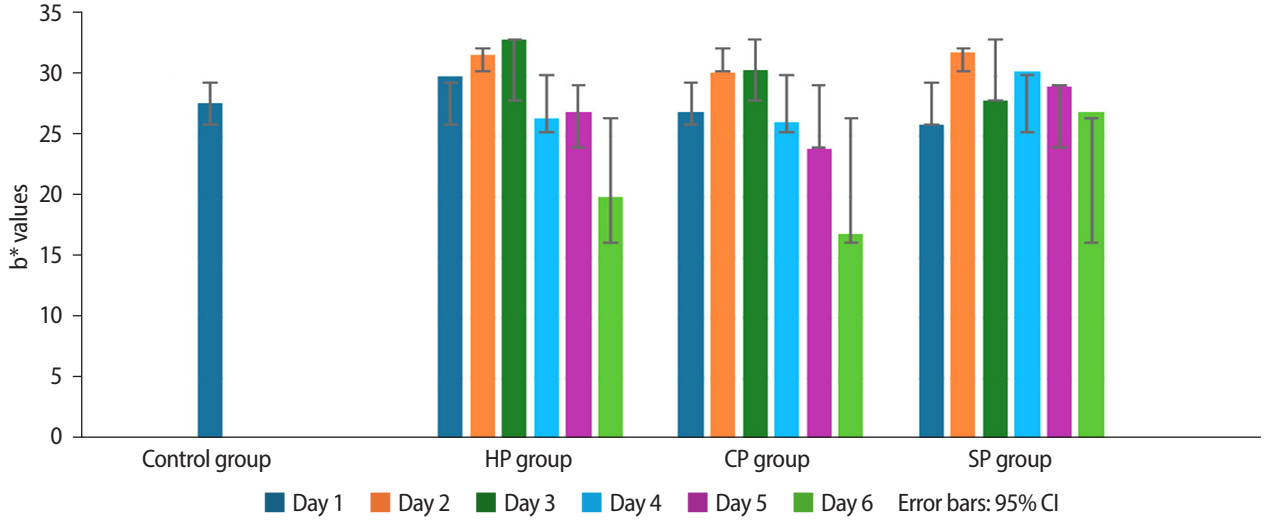

Figure 3. Daily change rates of mean b* values. Group definitions are provided in Table 1. CI, confidence interval.

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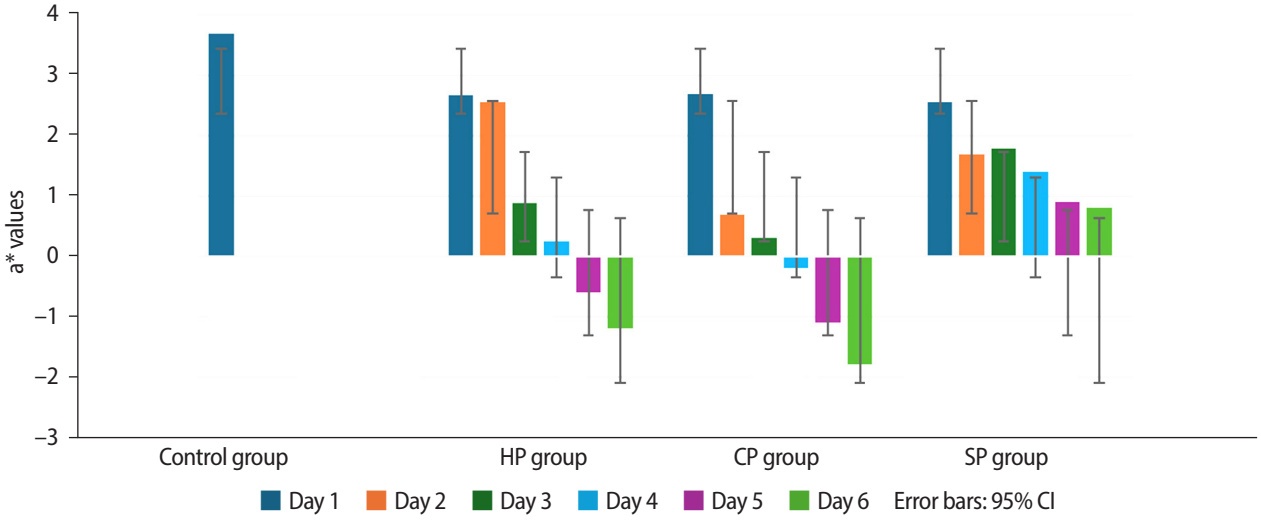

Figure 4. Daily change rates of mean a* values. Group definitions are provided in Table 1. CI, confidence interval.

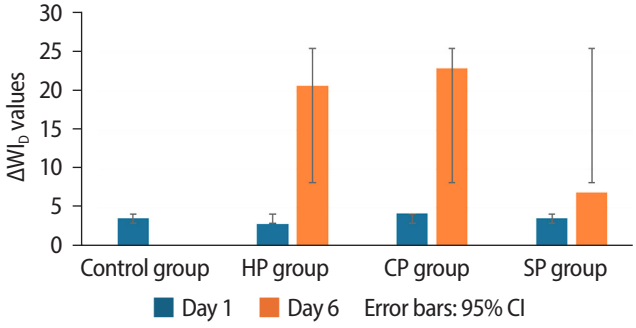

Figure 5. Whiteness index (WI_D) values before and after bleaching. Group definitions are provided in Table 1. CI, confidence interval.

In order to understand the variation in tooth color, it is necessary to understand the elements that determine color. Munsell defines color in terms of three elements: hue, value, and chroma. In contrast, the CIE defines color through a color system that uses three levels to express the coordinates of intersection (L^*: lightness; a^*: reddish-green; b^*: yellowish-bluish; ΔE: the amount of difference between two colors). Therefore, the identification of color by its coordinates facilitates more accurate results [28]. The ΔE value is subsequently calculated using these coordinates to express the difference between the two colors. According to extant literature, the decision was made to employ the CIEDE 2000 formula for the calculation of the ΔE value in the present study, as it has been demonstrated to accentuate more perceptible differences in comparison to the CIELAB formula [29]. Historically, if ΔE was determined to be greater than 3.3, it was considered sufficient to differentiate these two colors by the human eye. However, in this study, the current average threshold values of 0.8 for perceptibility and 1.8 for acceptability were employed as reference values [30].

The interpretation of the delta E value as a metric for change in color provides a robust indication of the efficacy of a bleaching treatment. Further validation of this metric is provided by the whitening index, which has been demonstrated to offer enhanced analytical power. The CIELAB-supported whitening index developed by Pérez *et al.* [27] has been evaluated in comparison to numerous other whitening indices and has been shown to be a reliable indicator. In our study, we have also examined the extent of tooth bleaching using the WI_D, providing a comprehensive assessment of the treatment's effectiveness.

A comprehensive examination of the study's outcomes reveals that the efficacy of three different bleaching agents varied over time. The most pronounced color change was observed in the Carbopol groups, followed by the HP and SP groups, respectively (Table 3, Figure 1). In a review of the results of studies comparing different bleaching agents conducted by Frank *et al.* [31], SP showed lower efficacy compared to CP and HP. However, no significant difference was found between CP and

Table 5. Evaluation of recoloration after bleaching

Color difference	Group 1	Group 2	Group 3	Group 4	*p*-value
ΔE_{00}	4.67 ± 3.44	19.78 ± 13.46	24.43 ± 14.01	24.35 ± 8.21	<0.001

Values are presented as mean ± standard deviation.
Group definitions are provided in Table 2.

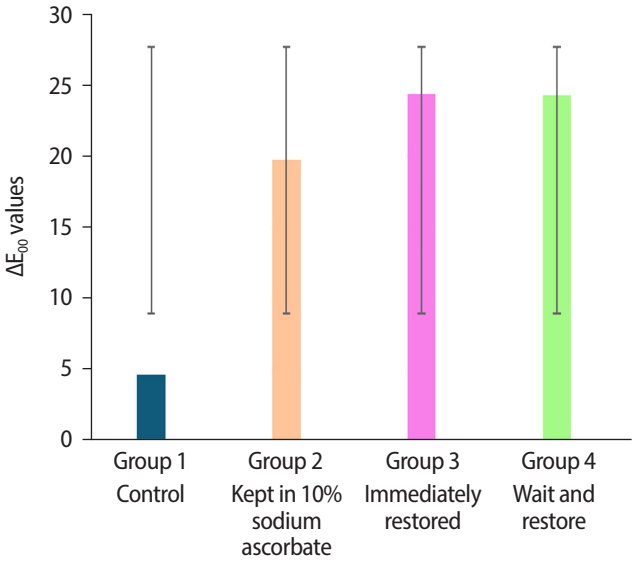

Figure 6. Amount of ΔE change of groups after recoloring. Group definitions are provided in Table 2. CI, confidence interval.

HP. If the results of our study are compared with this review, while SP obtained compatible results in terms of lower efficacy, CP showed more bleaching efficacy than HP in our study. In this respect, the results of the study are not compatible with the meta-analysis.

In an acidic environment, HP undergoes decomposition, yielding oxygen ions and hydroxyl free radicals. Conversely, within an alkaline environment (specifically between 9.5 and 10.8 on the pH scale), oxidation forms hydroperoxyl free radicals and enhances the bleaching effect [31,32]. Numerous studies have demonstrated that SP can effectively whiten the teeth without causing damage to the surrounding tissues. Nevertheless, a significant body of clinical studies has indicated that the bleaching effect is gradual [33]. In clinical settings, the preparation of the SP-superoxol mixture in the correct proportions and its subsequent application to the cavity without oxidation can pose a significant challenge. This may hinder the achievement of the desired degree of whiteness with SP.

In a clinical study, Keçeci [34] compared the efficacy of HP gel (Opalescence Endo) with that of a SP-superoxol mixture. The results indicated that while the HP gel produced visible whitening by day 2, the SP-superoxol mixture did not reach the desired level of whiteness until day 8. In our study, HP gel achieved maximum whitening by day 4; however, the SP-superoxol mixture failed to accomplish the desired whitening by day 8. These findings are consistent with the results reported in Keçeci's investigation.

The L^* value represents the lightness-darkness coordinate of color, and an increase in this value is anticipated throughout the bleaching treatment. In the present study, a statistically significant difference in L^* values was observed among the groups. The most notable increase in L^* value was recorded in the CP group, whereas the least significant increase occurred in the SP group.

In the context of bleaching treatments, a reduction in the b^* value is desirable to minimize the yellowish tones of the teeth. The results of this study indicate that the b^* value initially increased during the initial days of the bleaching process before beginning to decline after the third day. This initial increase may be attributed to the formation of by-products resulting from the breakdown of hemosiderin, a blood-derived substance, which contributes to the early yellowing observed during the bleaching process. Alternatively, yellow pigments may undergo decomposition at a later stage of the treatment.

The a^* value reflects the red-green coordinate of color, with the expectation that initially elevated values will decrease over time. A comparative analysis of the mean a^* values demonstrates a significant discrepancy between the study groups and the control group. Within each experimental group, the most pronounced decrease in mean a^* value is observed in the CP group, followed by the HP group, while the SP group exhibited the least significant reduction.

The outcome of the bleaching procedure is often assumed to be permanent; however, color reversion is a

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common occurrence. Howell [35] noted that "the more challenging the bleaching process, the more difficult it is to maintain color stability." Numerous studies have identified the presence of microscopic surface defects in enamel and the development of subsurface microporosity as the primary contributors to color recurrence [36].

In an *in vivo* study involving 26 bleached teeth, Deliper and Bardwell [37] monitored tooth color at 6-month intervals over a 2-year period, concluding that tooth color deteriorated by 19% due to the effects of devitalized bleaching. Conversely, an *in vitro* study conducted by Farawati *et al.* [38] found no significant difference in recoloring between bleached and unbleached teeth.

In the present study, however, a significant difference in recoloration was observed between bleached and unbleached teeth. This finding stands in contrast to the results reported by Farawati *et al.* [38], highlighting the ongoing debate regarding the durability of bleaching outcomes and the factors that influence color stability.

A significant challenge that impedes the effectiveness of bleaching treatments is the rapid recoloring that often occurs posttreatment, a phenomenon that is both undesirable and multifactorial in nature [27,28]. The present study aimed to determine whether there is a difference in color return between bleached and unbleached teeth by employing the wine-coloring method, which has been recognized in the literature as one of the most effective techniques for assessing color recurrence [26]. To achieve this objective, the study investigated whether the application of a sodium ascorbate solution to neutralize HP in bleached teeth could delay the return of color for up to 1 week.

In their study involving 72 bovine teeth, Türkün *et al.* [39] reported that the application of 10% sodium ascorbate gel for 60 minutes yielded optimal effects on bond strength following bleaching. Research on post-bleaching bond strength suggests that a delay of 24 hours to 3 weeks is advisable to mitigate the effects of HP on bonding efficacy. Freire *et al.* [40] found no significant difference in bond strength when comparing delayed bonding to immediate bonding in conjunction with the use of antioxidants.

Despite this, there remains a paucity of studies investigating the impact of sodium ascorbate on color stability after bleaching. The present study sought to ascertain whether sodium ascorbate indirectly influences recoloration by affecting energy exchange on the tooth surface and the sealing efficacy of composite restorations. Notably, an increased incidence of recoloring was observed in the bleached teeth group compared to the control group. Furthermore, no statistically significant differences were found between delaying restoration for one week to allow for HP neutralization, the application of sodium ascorbate as an antioxidant, or immediate restoration application.

It is important to highlight that the current study evaluated three distinct bleaching agents, all of which contained HP. The variation in bleaching efficacy observed can be attributed to the differing concentrations of HP within these formulations and the resultant by-products of the bleaching reactions.

CONCLUSIONS

The findings of this study indicate that HP, CP, and SP gels demonstrate significant variability in terms of bleaching speed and effectiveness, with CP exhibiting the highest bleaching efficiency. Regarding the issue of post-bleaching discoloration, it was noted that the application of sodium ascorbate or the neutralization of HP does not effectively mitigate recoloration. Additionally, bleached teeth displayed a greater tendency for recoloration compared to unbleached teeth.

In light of these findings and the distinct characteristics of the bleaching agents, particularly their varying HP concentrations and the subsequent alterations in residual HP levels, a new avenue for research has emerged. Future studies are planned to explore innovative materials that may impede color recurrence, thereby providing a comprehensive approach to the management of bleaching-induced discoloration.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Formal analysis, Funding acquisition: Türkün M. Investigation, Methodology, Project administration, Resource, Software: Aladağ A. Supervision, Validation: Demirbaş A. Visualization: Arslan G. Writing - original draft: Arslan G. Writing - review & editing: All authors. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are available from the corresponding author upon reasonable request.

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