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Original Article

Effect of hydrogen peroxide concentration on plasma arc-activated tooth bleaching: An in vitro study

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KEYWORDS
Tooth bleaching;
Hydrogen peroxide;
Plasma arc;
Microhardness;
Surface roughness

Abstract *Background/purpose:* Tooth bleaching was a conservative treatment compared with veneer and crown restorations that causes damage of teeth structure. This study evaluated the effectiveness of different concentrations of hydrogen peroxide combined with plasma arc activation for tooth whitening, focusing on tooth shade, microhardness, and surface roughness.
Materials and methods: The extracted teeth were standardized to ensure consistent surface conditions. They were bleached using various concentrations of 20 %—35 % hydrogen peroxide, with or without plasma arc activation. After the bleaching process, the shade, microhardness, and surface roughness of the teeth were measured before, during, and after the first and fourth bleaching cycles.
Results: The concentration of hydrogen peroxide significantly affected tooth color changes following a single plasma arc bleaching cycle. After the fourth cycle, all concentrations except for the 23 % hydrogen peroxide showed effects on tooth color and microhardness due to plasma arc activation, with roughness being the most notably impacted indicator. Therefore, while plasma arc treatment enhanced the efficacy of tooth whitening, it also significantly reduced microhardness, especially within the hydrogen peroxide concentration range of 26 %—35 %.
Conclusion: We suggest using a 26 % peroxide solution instead of high-concentration hydrogen

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peroxide, activated by a plasma arc, to achieve the same teeth whitening results while minimizing damage to the tooth surface.

Introduction

The causes of tooth discoloration could be roughly divided into two categories: extrinsic and intrinsic discoloration.[1] The extrinsic discoloration only affected the enamel surface; on the other hand, the intrinsic discoloration was discoloration of the teeth's structure. The factors that cause extrinsic teeth discoloration usually come from everyday foods such as coffee, tea, soy sauce, smoking, or betel nut. These pigments accumulate on the surface of the enamel or in the pellicle layer of the enamel.[1,2] Intrinsic tooth discoloration occurs before a tooth erupts and can be caused by factors such as trauma, genetic disorders, or the use of medications like tetracycline and fluoride. One of the most common reasons for a change in tooth color is aging-related discoloration. As we age, secondary dentin, which is typically darker and less translucent, accumulates while the enamel thins. These changes combined lead to the natural darkening of teeth over time.

There are many ways to change the color of teeth today, such as teeth bleaching, veneers, and crown restorations. Among these treatments, teeth bleaching was a conservative way compared with veneer and crown restorations, which cause damage to the tooth structure. Besides, the restoration easily led to secondary caries. Tooth bleaching is a cost-effective and straightforward method for changing the color of teeth, especially when compared to veneers and crowns, which require more extensive tooth preparation. There are two primary methods for tooth bleaching: home bleaching and in-office bleaching.

Home bleaching involves using a mouthguard filled with a low-concentration peroxide. The bleaching process takes longer to achieve the desired results when the concentration is lower. While home bleaching can produce results comparable to in-office treatments, it largely depends on the patient's adherence to the treatment schedule and requires consistent, uninterrupted application. If treatments are not completed as directed, the change in tooth color may not be satisfactory. Additionally, bleaching gels can be irritating and potentially harmful if used without professional supervision.

In-office bleaching typically uses high-concentration (30—35 %) hydrogen peroxide and is performed under the supervision of a dentist and is often combined with light activation for more effective whitening, such as using lasers, LED lamps, or plasma arc lamps to activate peroxide radicals. These light therapies produce a high concentration of reactive oxygen species (ROS) in a short amount of time, which theoretically enhances the bleaching effect.[3] However, Hein et al. found that light does not significantly influence the whitening outcome.[4] Since the results of in-office bleaching are visible immediately after treatment, this approach tends to improve patient satisfaction.

In the past, the mechanisms behind tooth whitening were a topic of scientific debate. However, recent research has clarified the key chemical processes that contribute to the appearance of whiter teeth. The main mechanism involves a complex oxidation reaction that breaks down pigmented molecules within the tooth structure, though other factors also play a role in the final result. Currently, it is understood that peroxides undergo oxidation, which releases superoxide radicals. These radicals break down pigment molecules, reducing them from larger to smaller forms and converting organic pigments, such as carbon ring structures, into non-pigmented, water-soluble structures.[5—8] While hydrogen peroxide and carbamide peroxide are commonly used bleaching agents, hydrogen peroxide stands out due to its low concentration and effectiveness. It results in a noticeable change in tooth color before and after treatment, making it a popular choice for in-office bleaching procedures.[9] Higher peroxide concentrations resulted in a greater decrease in enamel surface hardness.[6] Furthermore, after light activation, higher peroxide concentrations also resulted in lower pH values, leading to increased surface roughness after tooth bleaching.[10,11] This study aimed to investigate the effects of various concentrations of hydrogen peroxide combined with plasma arc activation on tooth bleaching. The focus was on evaluating changes in tooth color, microhardness, and surface roughness. The objective was to find an effective clinical bleaching regimen that achieves optimal results while minimizing damage to the tooth surface and to compare the effects of four cycles with one treatment cycle to verify its necessity.

Materials and methods

Tooth preparation

The study received approval from the Institutional Review Board at Kaohsiung Medical University Hospital (KMUH-IRB-980329). A total of twenty intact human maxillary premolars were used in this study. These teeth were extracted as part of orthodontic treatment and were free of restorations, root canal treatment, cracks, decalcification, or dentinogenesis imperfecta. After extraction, the teeth were promptly stored in saline at room temperature until further use. The teeth were then dissected at the cementoenamel junction to separate the crowns from the roots. The crowns were sectioned buccolingually, resulting in six

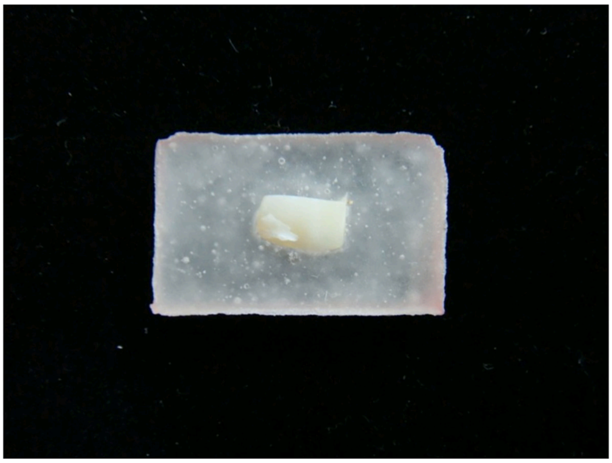

Figure 1 The tooth sample was mounted in the resin with an area of 2 mm × 2 mm.

Figure 2 Samples under plasma arc irradiation exposure. The distance between the plasma arc lamp bleaching machine and the tooth samples was 5 mm.

sections obtained from each tooth, for a total of 120 section slices.

The sections were embedded in resin (Hygenic orthodontic resin, Colten In., Cuyahoga Falls, OH, USA) with the enamel side facing upward to prepare the specimens, and only the enamel was exposed in each sample (Fig. 1). To promote uniformity, the exposed enamel area was kept as horizontal as possible. A square area, measuring approximately 2 mm × 2 mm, was scratched onto the surface, with the lower edge positioned 2—4 mm away from the junction of the cementum and enamel. This designated area served as the measurement zone for various values before and after the whitening treatments. Each slice was polished with pumice powder (Pumice fine, Miltex® Instruments, Princeton, NJ, USA) and then stored in normal saline until measurement. The samples needed to be air-dried prior to measurement. Before the bleaching procedure, the color shade, microhardness, and average surface roughness of each specimen were assessed.

A total of one hundred twenty tooth specimens were randomly divided into two groups: the pre-bleaching specimens that received plasma arc activation (T0A) and unexposed original specimens (T0B) that were treated with bleaching only. The bleaching was carried out using the Everbrite™ dental clinic tooth whitening kit (DentAmerica Asia Inc., Taipei, Taiwan) in conjunction with a light device (Litex™ 685, DentAmerica Asia Inc.) featuring plasma arc irradiation. The distance between the plasma arc bleaching device and the tooth specimens was set at 5 mm (Fig. 2). In the non-irradiated group, the tooth specimens were treated with bleaching solution alone, without plasma arc irradiation. Six sections from each tooth were randomly assigned to different concentrations of bleaching agent, containing 20 %, 23 %, 26 %, 29 %, 32 %, and 35 % hydrogen peroxide. According to the manufacturer's instructions, 2 ml of hydrogen peroxide at each concentration was mixed with the photoinitiator for 30 s. The mixed gel was then applied to the teeth for 10 min to a thickness of approximately 2 mm. Following application, the teeth were cleaned with normal saline for 15 min using an ultrasonic cleaner (Ultrasonic steri-cleaner, Leaderal Ltd, New Taipei, Taiwan). The teeth underwent one and four bleaching cycles, starting at T0A and T0B, with treatments that included plasma arc (T1A and T4A), and without plasma arc treatment (T1B and T4B). Measurements of tooth color, microhardness, and surface roughness were taken after the first and fourth bleaching cycles.

Measurement of the tooth shade

Tooth color was primarily measured using a colorimeter (ShadeEye NCC Dental Chroma Meter, Shofu Inc., Kyoto, Japan), with a tooth color guide (VITA classical shade guide, VITA Zahnfabrik, Bad Säckingen, Germany) as an additional tool.

Measurement of the microhardness

The microhardness of Vickers hardness number (VHN) was measured at three points with a 500 μm interval from the outer surface using a Vickers microhardness indenter (HMV-2, Shimadzu Co., Kyoto, Japan) under a load of 200 gf.

Measurement of the surface roughness

The sample was mounted on the atomic force microscope (AFM) stage in semi-contact mode (NanoMan NS4+D3100, Digital Instrument, Taipei, Taiwan). The microscope settings were as follows: voltage set to 0.2 V, probe magnification at 20, a scan area of 10 × 10 μm^2, and a scan frequency of 1.01 Hz. The probe model used was NSG 01 (NT-MDT). The average surface roughness was assessed by randomly measuring three different areas within a ruled grid both before and after the bleaching process.

Statistical analysis

Paired t-tests were conducted to analyze changes in tooth color of shade, microhardness, and surface roughness during each bleaching cycle. The effects of varying concentrations and plasma arc exposures on these same factors were evaluated using the Kruskal—Wallis test, with a

Table 1 Statistical comparison of tooth shade, microhardness, and surface roughness between after one round of bleaching and after bleaching four cycles between and pre-bleaching in each hydrogen peroxide concentration.

	T1A versus T0A			T4A versus T0A			T1B versus T0B			T4B versus T0B		
	S	H	R	S	H	R	S	H	R	S	H	R
20 %	*	*		*	*	-		*	*		*	-
23 %		*	*	*	*	-	*	*	*	*	*	-
26 %	*	*	*	*	*	-	*	*	*	*	*	-
29 %	*	*	*	*	*	-	*	*	*	*	*	-
32 %	*	*	*	*	*	-	*	*	*	*	*	-
35 %	*	*	*	*	*	-	*	*	*	*	*	-

T0:Pre-bleaching; T1:After one round of bleaching; T4: After four bleaching cycles; A: With plasma arc irradiation; B: No plasma arc irradiation; S: Tooth shade; H: Microhardness; R: Surface roughness; *: Statistical significance ($P < 0.05$).

Table 2 Analysis of the effect of hydrogen peroxide concentration on tooth shade, microhardness, and surface roughness.

	T1A			T4A			T1B			T4B		
	S	H	R	S	H	R	S	H	R	S	H	R
Concentration	*	*		*		—				*		—

T1: After one round of bleaching; T4: After four bleaching cycles; A: With plasma arc irradiation; B: No plasma arc irradiation; S: Tooth shade; H: Microhardness; R: Surface roughness; *: Statistical significance ($P < 0.05$).

Table 3 Statistical comparison of tooth color, microhardness, and surface roughness after one and four cycles of bleaching at various hydrogen peroxide concentrations.

	T4A versus T1A			T4B versus T1B		
	S	H	R	S	H	R
20 %	*	*	-		*	-
23 %		*	-		*	-
26 %	*	*	-	*	*	-
29 %	*	*	-		*	-
32 %	*	*	-		*	-
35 %	*	*	-	*	*	-

T1: After one round of bleaching; T4: After four bleaching cycles; A: With plasma arc irradiation; B: No plasma arc irradiation; S: Tooth shade; H: Microhardness; R: Surface roughness; *: Statistical significance ($P < 0.05$).

significant difference defined as $P < 0.05$. The statistical comparison results are shown in Tables 1—4. All statistical analyses were performed using SPSS 14.0 (IBM Co., Armonk, NY, USA).

Table 4 Analysis of the effects of hydrogen peroxide concentration, plasma arc irradiation, and their interaction on tooth shade, microhardness and surface roughness.

	T1			T4		
	S	H	R	S	H	R
Plasma arc irradiation				*	*	—
Hydrogen peroxide concentration		*		*		—
Interaction						—

T1: After one round of bleaching; T4: After four bleaching cycles; S: Tooth shade; H: Microhardness; R: Surface roughness; *: Statistical significance ($P < 0.05$).

Results

Plasma arc irradiation group

After one cycle of bleaching, the minimum shade value of teeth treated with 29 % hydrogen peroxide was 5.50 ± 2.01, while the maximum shade value for teeth treated with 20 % hydrogen peroxide was 8.30 ± 2.63 (Fig. 3). The minimum microhardness value for teeth in the 35 % hydrogen peroxide group was 151.90 ± 32.65 VHN. However, the maximum microhardness value for teeth in the 20 % hydrogen peroxide group was measured at 245.86 ± 35.24 VHN (Fig. 4). In terms of surface roughness, the minimum value was observed in the 20 % hydrogen peroxide group, measuring 321.70 ± 87.35 nm, while the maximum roughness was noted in the 35 % hydrogen peroxide group at 400.55 ± 52.42 nm (Figs. 5 and 6). Analysis of tooth shade, microhardness, and surface roughness after one round of bleaching in the plasma arc-irradiated groups revealed no significant change in tooth shade compared to the pre-bleaching shade (T0A) in the 23 % hydrogen peroxide group (paired t-test, $P > 0.05$). However, significant changes were noted in the tooth shade in the other hydrogen peroxide concentration groups (paired t-test, $P < 0.05$). The microhardness results indicated significant changes across all concentrations of hydrogen peroxide (paired t-test, $P < 0.05$). In the analysis of surface roughness, the group treated with 20 % hydrogen peroxide did not show a significant change compared to pre-bleaching results (paired t-test, $P > 0.05$). In contrast, the other groups with different hydrogen peroxide concentrations demonstrated significant changes in bleaching when compared to the results after one round of bleaching (paired t-test, $P < 0.05$). The statistical analysis is shown in Table 1.

After one round of bleaching combined with plasma arc irradiation, the concentration of hydrogen peroxide significantly affected both tooth shade and microhardness (Kruskal—Wallis test, $P < 0.05$). As the concentration of hydrogen peroxide increased, the changes in tooth shade and microhardness became more pronounced. However, the concentration of hydrogen peroxide did not have a significant impact on the roughness of the tooth surface (Kruskal—Wallis test, $P > 0.05$). The statistical analysis is shown in Table 2.

After four cycles of bleaching combined with plasma arc irradiation, the minimum tooth shade achieved in the 35 %

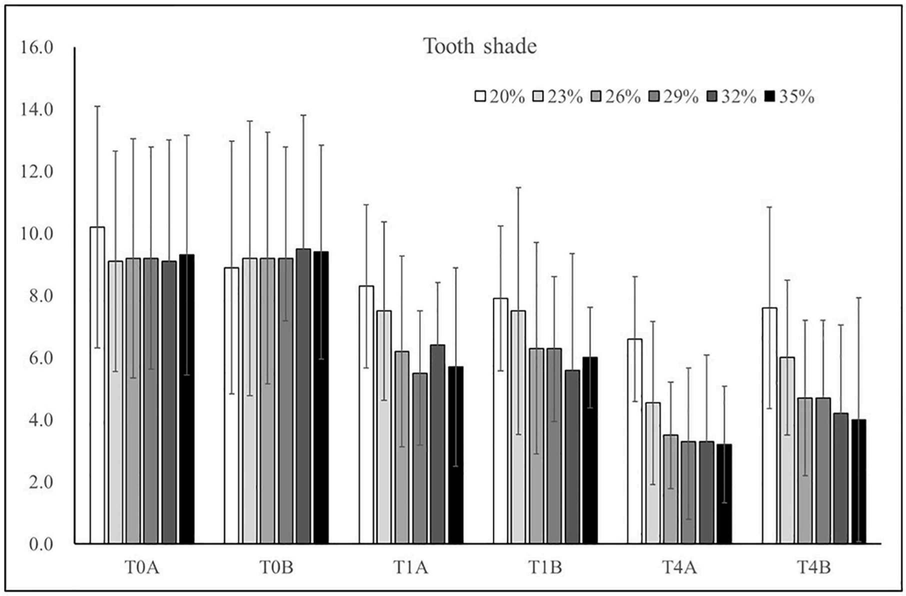

Figure 3 Changes in teeth shade before bleaching, after one round of bleaching, and after four bleaching cycles with and without plasma arc irradiation exposure. Each column represents the mean and standard deviation. T0: Pre-bleaching, T1: After one round of bleaching, T4: After four bleaching cycles, A: With plasma arc irradiation, B: No plasma arc irradiation.

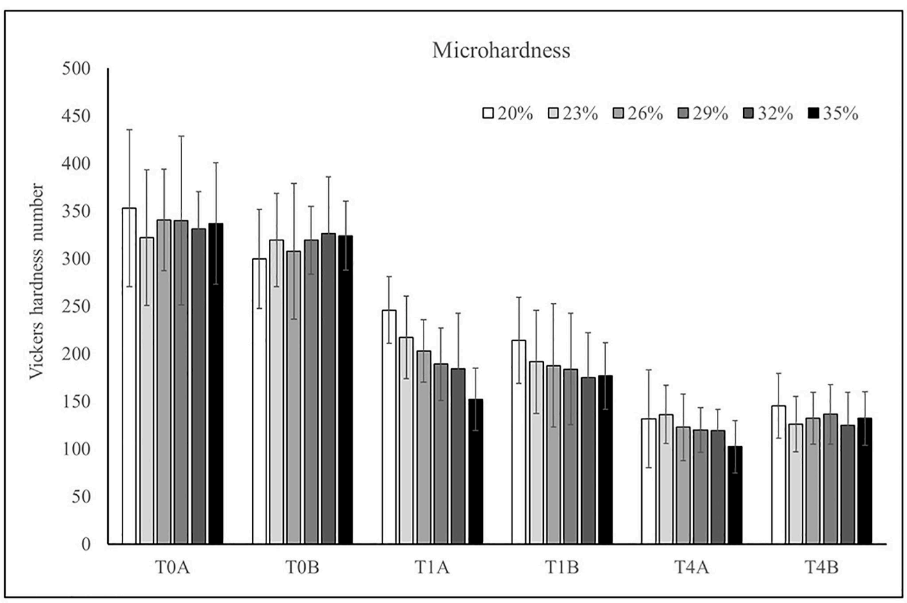

Figure 4 Changes in teeth microhardness before bleaching, after one round of bleaching, and after four bleaching cycles with and without plasma arc irradiation exposure. Each column represents the mean and standard deviation. T0: Pre-bleaching, T1: After one round of bleaching, T4: After four bleaching cycles, A: With plasma arc irradiation, B: No plasma arc irradiation.

hydrogen peroxide group was 3.20 ± 1.87, while the maximum tooth color in the 20 % hydrogen peroxide group reached 6.60 ± 2.01 (Fig. 3). The lowest tooth microhardness was measured in the 35 % hydrogen peroxide group at 102.15 ± 27.38 VHN, while the highest in the 23 % hydrogen peroxide group was recorded at 136.03 ± 30.80 VHN (Fig. 4). Overall, after four cycles of bleaching, the tooth shade and microhardness in all hydrogen peroxide concentrations showed significant differences compared to measurements taken before bleaching (paired t-test, $P < 0.05$). The statistical analysis is shown in Table 1.

After four cycles of bleaching, the concentration of hydrogen peroxide significantly influenced tooth shade (Table 2, Kruskal—Wallis test, $P < 0.05$). Higher concentrations resulted in more pronounced changes in tooth shade. In contrast, the concentration of hydrogen peroxide had no effect on tooth microhardness (Table 2, Kruskal—Wallis test, $P > 0.05$). Furthermore, the effects of

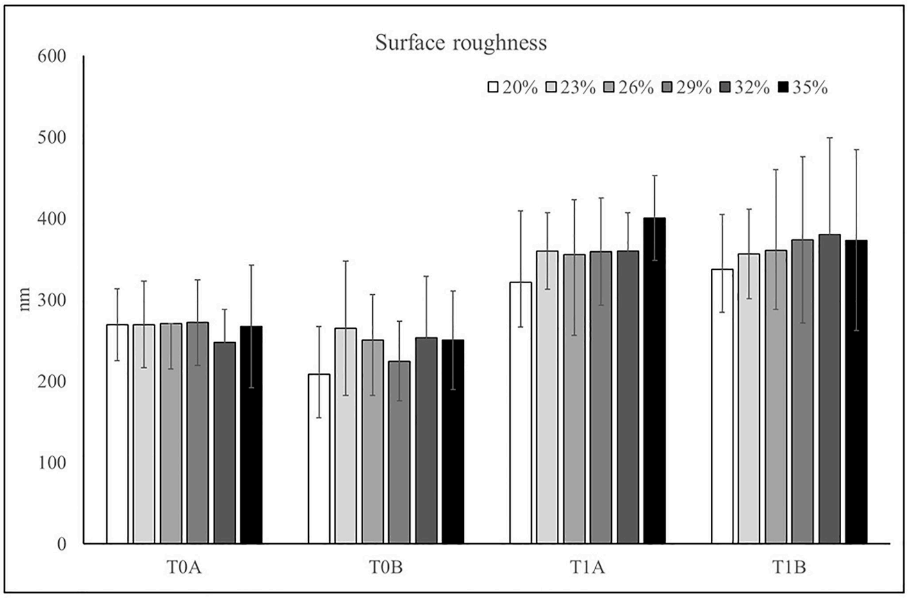

Figure 5 Changes in teeth surface roughness before bleaching and after one round of bleaching with and without plasma arc irradiation exposure. Each column represents the mean and standard deviation. T0: Pre-bleaching, T1: After one round of bleaching, A: With plasma arc irradiation, B: No plasma arc irradiation.

different hydrogen peroxide concentrations on tooth shade and microhardness after one and four cycles of bleaching with plasma arc irradiation were significantly different (Table 3, paired t-test, $P < 0.05$).

No plasma arc irradiation group

After one round of bleaching, the minimum shade value of the teeth was observed in the 32 % hydrogen peroxide group, measuring 5.60 $\pm$ 3.75, while the maximum was noted in the 20 % hydrogen peroxide group at 7.90 $\pm$ 2.33 (Fig. 3). The minimum microhardness was recorded in the 32 % hydrogen peroxide group at 174.60 $\pm$ 47.31 VHN, with the highest value found in the 20 % hydrogen peroxide group at 214.13 $\pm$ 45.30 VHN (Fig. 4). The lowest tooth surface roughness was identified in the 23 % hydrogen peroxide group at 356.34 $\pm$ 54.84 nm, whereas the highest was observed in the 32 % hydrogen peroxide group at 380.52 $\pm$ 118.44 nm (Figs. 5 and 6). There was no significant difference in tooth shade between the 20 % hydrogen peroxide bleaching group and the pre-bleaching baseline values (T0B) (paired t-test, $P > 0.05$). However, the tooth shade in all other hydrogen peroxide concentration groups changed significantly compared to pre-bleaching (paired t-test, $P < 0.05$). Additionally, when compared with the pre-bleaching group, the surface roughness of the teeth increased significantly across the other concentration groups (paired t-test, $P < 0.05$). The statistical analysis is shown in Table 1. In one round of bleaching, the concentration of hydrogen peroxide did not significantly affect the shade, microhardness, or surface roughness of the teeth (Table 2, Kruskal–Wallis test, $P > 0.05$).

After four cycles of bleaching, the group that used 35 % hydrogen peroxide demonstrated the lowest tooth shade, averaging 4.00 $\pm$ 3.92. In contrast, the group that used 20 % hydrogen peroxide exhibited the highest tooth shade, with an average of 7.60 $\pm$ 3.24. Furthermore, the minimum tooth microhardness recorded in the 35 % hydrogen peroxide group was 102.15 $\pm$ 27.38 VHN, while the maximum microhardness was 136.03 $\pm$ 30.80 VHN in the 20 % hydrogen peroxide group (paired t-test, $P < 0.05$). The analysis showed that after four cycles of bleaching, both tooth shade and microhardness exhibited significant changes compared to pre-bleaching values across all groups with varying hydrogen peroxide concentrations (Table 1, paired t-test, $P < 0.05$). Furthermore, tooth color was influenced solely by the concentration of hydrogen peroxide (Table 2, Kruskal–Wallis test, $P < 0.05$), while the concentration did not have a significant effect on tooth microhardness (Kruskal–Wallis test, $P > 0.05$).

A comparison was conducted to evaluate the effects of one round of bleaching versus four bleaching cycles on tooth shade and microhardness (Table 3). The roughness measurements after four cycles were excluded from the analysis due to their unreliable values. The results indicated that only the 26 % and 35 % hydrogen peroxide concentrations significantly altered the tooth shade. In contrast, the 29 % hydrogen peroxide concentration notably affected the microhardness of the teeth (paired t-test, $P < 0.05$).

Overall comprehensive analysis

After completing one round of bleaching, we analyzed the effects of plasma arc irradiation, hydrogen peroxide concentration, and their interaction on tooth shade, microhardness, and surface roughness (Table 4). It was observed that tooth shade and surface roughness did not show any significant differences (Kruskal–Wallis test, $P > 0.05$). However, the concentration of hydrogen peroxide did have a significant impact on tooth microhardness (Kruskal–Wallis test, $P < 0.05$). After four bleaching cycles, both plasma arc

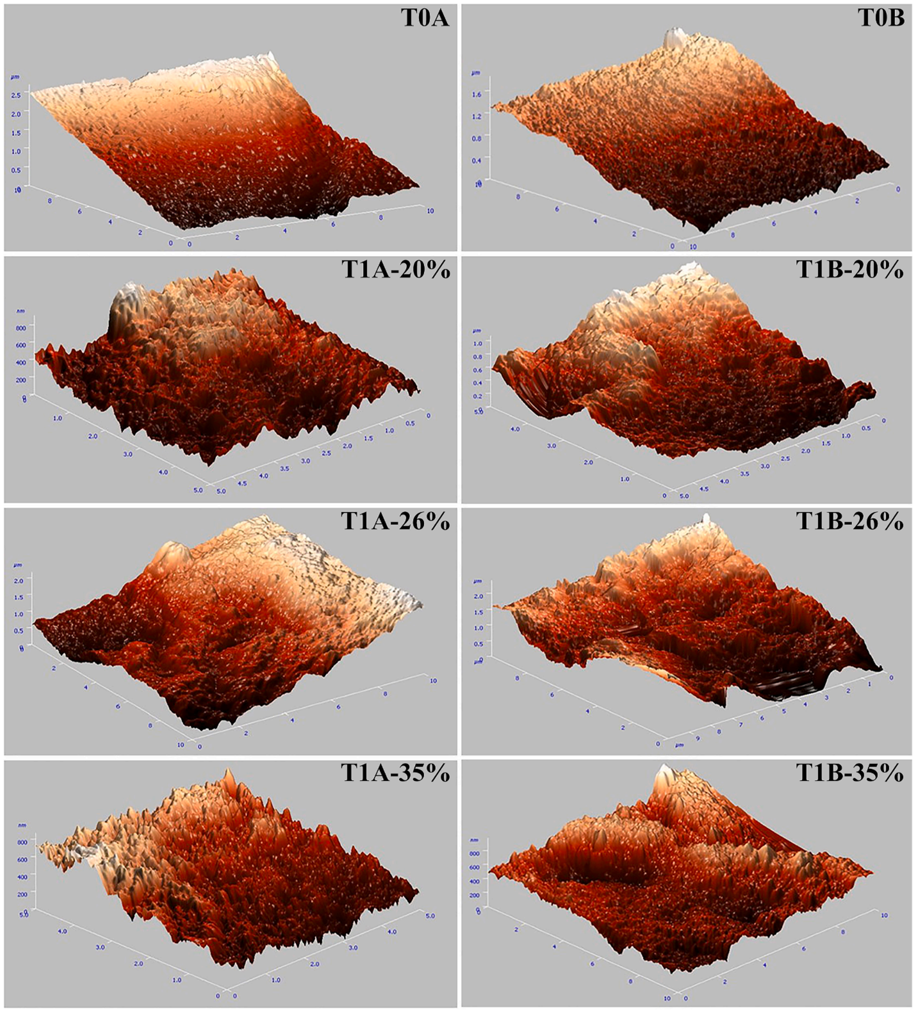

Figure 6 Teeth surface roughness before bleaching and after one round of bleaching with and without plasma arc irradiation exposure at 20 %, 26 %, and 35 % hydrogen peroxide concentrations in atomic force microscope (AFM) image. T0: Pre-bleaching, T1: After one round of bleaching, A: With plasma arc irradiation, B: No plasma arc irradiation.

irradiation and hydrogen peroxide concentration were found to affect tooth shade, while microhardness was influenced by the irradiation process (Kruskal—Wallis test, $P < 0.05$).

Discussion

To create aesthetically pleasing dental restorations, accurately representing tooth color is crucial. The first step in achieving the right restoration shade is to match the natural tooth color. In dental offices, the most common method for color matching is visual assessment using a dental shade guide.[12] However, the accuracy and precision of visual assessments were not high. According to the literature, approximately 44 %—63 % of patients believed that the restorations they received were a different color from the adjacent natural teeth.[13,14] To improve tooth color matching, colorimeters have been developed. These optical devices use filtered photodetectors to read the visible spectrum and measure the wavelengths of light reflected by an object to determine its color. They are user-friendly, reliable, and provide consistent measurements, unaffected by environmental conditions or light sources.[15,16] The ShadeEye NCC Dental Chroma Meter used in this study was a colorimeter. According to previous research, it demonstrated a precision of approximately 87.5 %—88.2 %.[17,18] It had the aforementioned advantages, and the results were presented in the color scale of the Vita Classical shade guide. In clinical applications, it was also very convenient for communicating with patients undergoing bleaching treatment.

Human tooth shades can be categorized into four main groups—A, B, C, and D—according to the Vita shade guide system, which is commonly used in dental clinics. Each group is further divided into specific shades: A1, A2, A3, A3.5, A4, B1, B2, B3, B4, C1, C2, C3, C4, and D2, D3, D4, based on chroma. When arranged by value, the tooth shades are ordered as follows: B1, A1, B2, D2, A2, C1, C2, D4, A3, D3, B3, A3.5, B4, C3, A4, and C4 (Fig. 7). Shades B1 to C4 were numbered sequentially from 1 to 16. The color scale of the Vita shade guide was used to track the degree

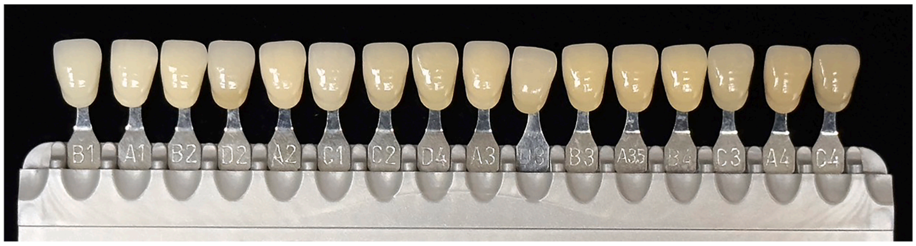

Figure 7 The Vita shade guide is arranged by value. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

of tooth shade change before and after teeth whitening. Since the naked eye is generally more accurate at judging value rather than hue, this study relied on the Vita shade guide to document the changes in tooth color value.

After one round of bleaching, nearly all concentrations showed significant differences in tooth shade between the plasma arc irradiation group and the no plasma arc irradiation group, except for 23 % in the irradiation-exposure group and 20 % in the no irradiation-exposure group. The shade changed approximately three levels in both the plasma arc irradiation group and the no plasma arc irradiation group. When analyzing the effect of concentration on tooth shade, changes in shade tended to increase in the plasma arc irradiation group as the concentration increased. However, in the no plasma arc irradiation group, the effect of increased concentration on tooth shade change was less pronounced. This suggests that neither plasma arc irradiation nor hydrogen peroxide concentration significantly influenced tooth shade changes after just one round of bleaching (Kruskal–Wallis test, $P > 0.05$). After undergoing four cycles of bleaching, tooth shade changes continued to increase with each concentration of hydrogen peroxide, regardless of exposure to plasma arc irradiation. In the group exposed to plasma arc radiation, the average shade change was approximately six degrees, while in the group without plasma arc irradiation, it was about five degrees. Both the concentration of hydrogen peroxide and exposure to plasma arc irradiation significantly influenced the changes in tooth shade (Kruskal–Wallis test, $P < 0.05$). Notably, both groups experienced an increase in shade change with higher concentrations of hydrogen peroxide. However, the rate of shade change slowed down once the concentration exceeded 26 %. This indicates that there was no significant difference in bleaching efficiency between the concentrations of 26 % and 35 %. Additionally, when the concentration of hydrogen peroxide was above 26 %, the difference in tooth shade between the groups exposed to plasma arc irradiation and those not exposed diminished. This suggests that using 26 % hydrogen peroxide in combination with plasma arc irradiation can produce results similar to those achieved with 35 % hydrogen peroxide alone. Although the difference in tooth shade between the two groups was not statistically significant, further research is necessary to evaluate the stability of tooth shade, as existing literature suggests that irradiation exposure may contribute to greater color stability.[19]

The shade of teeth is primarily determined by the combination of individual colors of dentin and enamel, along with their optical characteristics.[20] When a bleaching agent comes into contact with the enamel, it induces both physical and chemical changes to the inorganic and organic components within the enamel. Specifically, hydrogen peroxide interacts with the organic substances in the enamel to produce smaller, single-chain molecules, which alter the color of the teeth.[21] Additionally, oxidation can occur in the inorganic components of the enamel.[21–23] Research has demonstrated that hydrogen peroxide can affect the crystal structure of enamel. Changes in this structure can impact the optical properties of the teeth, leading to noticeable color changes. When the bleaching agent permeates through the interprismatic spaces of the enamel and reaches the dentin, both the organic and inorganic substances in the dentin also undergo oxidation reactions. The bleaching agent can release reactive oxygen species, which break the double bonds of organic and inorganic compounds within the dentinal tubules.[24] Besides the compositional changes in the dentin due to oxidation, morphological changes also occur, such as increased permeability.[21] Changes in composition and shape may contribute to changes in dentin color, which in turn affects tooth color. Generally, higher bleaching agent concentrations, longer application times, and improved penetration are associated with greater tooth shade changes. The results of this study are similar to those of previous studies.[25–27] Of note, a key observation is that changes in tooth shade tend to become less pronounced when peroxide concentrations exceed 26 %.

The microhardness of teeth significantly decreased at all concentrations after bleaching treatment. Initially, changes in microhardness were related to concentration, not plasma arc irradiation. However, after four bleaching cycles, microhardness continued to decline, with hardness changes linked to plasma arc irradiation rather than concentration. Some studies indicate that bleaching agents with photoinitiators reduce microhardness slightly more than those without.[28,29] In various experiments, calcium and phosphorus are often lost following contact with bleaching agents.[30–32] Other studies have also shown that the organic component of enamel increases while the inorganic hydroxyapatite decreases after teeth bleaching.[23] Mature enamel consists of approximately 96 % inorganic minerals and 4 % organic matter and water, with hydroxyapatite being the primary inorganic component containing calcium ions. Due to its high mineral content, enamel exhibits significant hardness. The loss of these minerals may contribute to the decreased microhardness of teeth after the application of bleaching agents.[33] Additionally, hydroxyapatite can be affected by the pH level of the hydrogen peroxide solution used for bleaching. Enamel begins to demineralize when the pH ranges between 5.2 and 5.8.[34] More acidic pH levels, such as those found in some hydrogen peroxide gels, can lead to progressive demineralization of enamel, ultimately resulting in a reduction of teeth microhardness.[21,35]

After one round of bleaching, the surface roughness of the teeth increased in almost all concentrations, except for the 20 % concentration, in both the groups exposed to plasma arc irradiation and those not exposed. However, the changes in surface roughness were not related to the concentration of hydrogen peroxide or plasma arc irradiation exposure. The morphological changes in the enamel were associated with the pH of the bleaching agent, which affected the degradation of both the organic and inorganic structures of the enamel. The increase in roughness occurred due to the reorganization of enamel prisms, resulting from the oxidative effects of the bleaching agent at an acidic pH.[20] Microstructural images from the literature indicate that the number and diameter of acid-etched pores in tooth enamel increase, potentially leading to greater surface roughness with repeated bleaching.[36] However, further detailed experiments are needed to assess whether bleaching cycles actually affect surface roughness.

In summary, the concentration of hydrogen peroxide had a significant impact on changes in tooth shade. However, when the concentration exceeded 26 %, the difference in shade was minimal. After the bleaching cycle, both the shade and microhardness of the teeth were affected by exposure to plasma arc irradiation. While plasma arc irradiation enhanced the change in tooth shade, it also reduced the microhardness of the teeth. Additionally, the surface roughness of the teeth post-bleaching treatment was unaffected by either the concentration of hydrogen peroxide or the plasma arc irradiation process. We recommend using a 26 % hydrogen peroxide concentration instead of 35 %, along with plasma arc irradiation, to achieve the best change in tooth shade while minimizing potential damage to the teeth.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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