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In Vitro Effect of Sodium Bicarbonate on Tooth Discoloration

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Objectives The present experimental study aimed to assess the in vitro effect of sodium bicarbonate (SB) on tooth discolouration.
Methods Forty-five extracted anterior teeth were decoronated 2 mm apical to the cementoenamel junction. The crowns were immersed in tea solution for 7.5 days. The teeth were divided into three groups (n = 15 per group) on a random basis. The groups were exposed to either SB paste 94%, hydrogen peroxide (HP) 40%, or carbamide peroxide (CP) 45%. Then, teeth were bleached according to the manufacturers' instructions. Next, all tooth samples were immersed again in tea solution for 10 min. The CIE L*a*b* colour parameters of the teeth were evaluated at baseline (T1), after primary staining (T2), after bleaching (T3), and after re-staining (T4) using a spectrophotometer. The enamel surface morphology of one sample from each group was evaluated pre- and post-bleaching using scanning electron microscopy (SEM). Within-group and between-group comparisons were made using repeated measures ANOVA and Tukey's test.
Results 94% of cases had color change(ΔE) more than 3.5 with no enamel surface wear after Applying SB. HP showed a maximum bleaching effect of ΔE = 8.77. After re-staining, the SB group showed minimal staining (ΔE = 3.77) compared to the HP and CP groups.
Conclusion The present findings show that SB can chemically resolve tooth discolouration and prevent re-staining. Considering its low abrasiveness, optimal safety, low cost, antimicrobial activity, and availability, it seems to be ideal for use at home.
Keywords Carbamide Peroxide; Hydrogen Peroxide; Sodium Bicarbonate; Tooth Bleaching

Introduction

Demand for a beautiful smile is increasing worldwide. Tooth color is an important parameter in smile esthetics. [1] Thus, tooth bleaching agents and their effects on tooth structure remain interesting topics of research. [2]
Tooth bleaching is a more conservative treatment option than micro-abrasion and invasive restorative procedures for discolored teeth. [1,3] Several methods are available for tooth bleaching with different mechanisms of action. The efficacy of different methods depends on the type of staining that needs to be corrected. [4] Hydrogen peroxide (HP), carbamide peroxide (CP), and sodium perborate (SP) are commonly used for tooth bleaching. [5] The action mechanism of bleaching involves the oxidation of organic polymeric materials (pigments) resulting in tooth whitening. The free radicals generated from HP break the double bonds of organic pigments and convert them into achromatic materials with low molecular weight. [5-7] The generation of free radicals from HP can be accelerated by chemical agents, heat, and light. [6,7] Repeated use and high concentration of bleaching agents can cause tooth hypersensitivity, alter the enamel surface and cause its demineralization due to low pH. [8] Also, HP and CP along with carcinogens such as alcohol and tobacco can bring about genotoxic complications. [9]
Sodium bicarbonate (SB) with the chemical formulation of $NaHCO_3$ has long been used in traditional medicine for tooth bleaching. It is a sodium salt in combination with carbonic acid with only one acidic hydrogen replaced with sodium. [10] SB has long been used as an abrasive in toothpaste and recently gained popularity for tooth whitening. However, SB has lower abrasiveness than other abrasives such as calcium carbonate, calcium pyrophosphate, and silica. [11] On the other hand, SB is safe, low-cost, water-soluble, biocompatible with fluoride, and has a buffering capacity. [12] The use of toothpaste containing SB can whiten the teeth, effectively remove dental plaque and exert antibacterial activity in high concentrations. [12, 13] Ghassemi et al.[14] (2012) showed that SB can chemically prevent the re-staining of teeth.
In dental bleaching studies, the CIE L*a*b* color space is commonly used for colourimetry[1]. It has three color coordinates of L*, a*, and b*. The "L*" parameter represents lightness and can range from 0 indicating black to 100 indicating white. The "a*" parameter is reported as positive for redness or negative for greenness. The b* parameter is also reported as a positive value for yellowness or negative for blueness. [15] The color difference (ΔE) is often calculated to assess the color change. [16]
Based on the literature, there is a gap in information regarding the chemical bleaching effect of SB. Besides, bleaching is associated with some changes in the structure of the enamel surface. [17] Accordingly, the present in vitro study was conducted to assess the effect of SB on tooth discoloration as well as the enamel surface morphology before and after bleaching with SB.

Methods and Materials

During the current in vitro experiment, 45 extracted human maxillary and mandibular anterior teeth extracted for other purposes unconnected to this study were evaluated. This project was conducted under the approval of the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.RIDS.REC.1395.371). The teeth were disinfected with 5.1% sodium hypochlorite for 24 h and stored in saline until the experiment. They were then decoronated at 2 mm apical to the cementoenamel junction using a cylindrical high-speed diamond bur.

The inclusion criteria were sound human maxillary and mandibular teeth extracted for purposes not related to this study.

The exclusion criteria were caries, restorations, cracks, dental anomalies, and hypoplastic enamel defects. The calculated sample size of each group was 15 according to Ghassemi et al.[14] assuming alpha = 0.05, beta = 0.2, and study power of 80%.

The teeth were subjected to colorimetry at baseline (T1) and the L*, a*, and b* parameters were measured and recorded using a spectrophotometer (Ci6xNB/2013DJ880) with a grey background. Artificial staining was performed using the tea solution (black tea, Golestan, Tehran, Iran): 9 g of loose tea in 450 mL boiling distilled water left for 5 min. The weighing was performed by a digital scaler with 0.01 g accuracy (AND). Each tooth was immersed in 10 mL of tea solution for 7.5 days at room temperature. The tea solution was refreshed every day. After 7.5 days, the teeth were taken out of the solution and washed with distilled water. Then, colorimetry was performed again (T2), and the data were recorded before bleaching. For the bleaching stage, teeth were randomly divided into the three groups (n = 15) either receiving SB 94%, HP 40%, or CP 45%. The surface of all tooth samples was dried, and the bleaching material was applied on the buccal surface of the tooth according to the manufacturers' instructions. Table 1 presents the characteristics of the used bleaching agents. The 94% SB paste was prepared by adding 94 g of SB (weighed by a digital scale with 0.01 g accuracy) to 100 mL of distilled water. The paste was applied to the buccal surface with a thickness of 1 mm. This was repeated for 10 days, each time for 5 min. Following each time of paste application, the tooth was rinsed and stored in distilled water overnight. In the HP group, 40% HP (Opalescence Boost 40%, Ultradent Products, USA) was applied on the buccal tooth surface in 0.5 to 1 mm thickness for 20 min. The teeth were then rinsed and stored in distilled water until colorimetry. In the CP group, 45% CP (Opalescence Quick 45% PF, Ultradent products, USA) was applied on the buccal tooth surface with 1 mm thickness for 30 min. Then, tooth samples were rinsed and stored in distilled water until be used for colorimetry. After bleaching, colorimetry was performed again (T3). After the final bleaching step, the teeth were immersed again in the tea solution for 10 min and colorimetry was conducted for the last time (T4) to assess the tooth resistance to re-staining after bleaching.

Color change (ΔE) was calculated using the formula below:

$\Delta E = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{0.5}$

To analyze the enamel surface morphology,according to previous studies [8, 11, 14, 26] one sample was randomly selected from each group and its surface topography was evaluated pre- and post-bleaching treatment. Selection was done by simple randomization in which a number was given to each sample of each group and a blind examiner was asked to choose a number from each group. The enamel surface morphology was evaluated using SEM (FEI ESEM QUANTA 200/EDS EDAX SILICON DRIFE 2017).

Data were analyzed using SPSS version 22 (SPSS Inc., IL, USA). The normal distribution of data was evaluated using the Kolmogorov-Smirnov test. The mean L*, a*, b*, and ΔE were calculated and reported for each bleaching group. Within-group and between-group comparisons of colour change were conducted using repeated measures ANOVA and Tukey's test, respectively. P-value < 0.05 were considered as statistically significant.

Results

The L* parameter:

Table 1 presents the mean L* parameter in the three groups at different time points. Within-group comparison of the L* parameter in the SB group by repeated-measures ANOVA revealed no significant difference (P = 0.548) in this group at different time points. In the HP group, repeated measures ANOVA showed a significant difference only between T2 and T3 (p<0.05). In the CP group, the difference in L* parameter was significant between T2 and T4, and also between T3 and T4 (p<0.05).

Table 1- Mean l*, a*, and b* parameters in the three groups at different time points

Parameter	Group	T1	T2	T3	T4	P-value
L*	SB	55.33±3.97	52.86 ± 5.35	53.6 ± 6.2	54.67 ± 5.5	P = 0.548
	HP	58.19±5.83	53.5 ± 5.48	58.85 ± 5.63	59.88 ± 5.99	P = 0.016
	CP	58.05±4.61	55.16 ± 3.84	65.73 ± 3.7	61.49 ± 4.19	P = 0.001
a*	SB	1.63 ± 1.36	4.73 ± 1.96	3.86 ± 1.63	4.48 ± 1.86	P < 0.001
	HP	1.37 ± 1.33	4.45 ± 2.17	5.12 ± 0.91	2.22 ± 1.4	P < 0.001
	CP	1.34 ± 0.97	3.88 ± 1.6	1.42 ± 1.24	1.95 ± 1.1	P < 0.001
b*	SB	12.48 ± 4	12.17 ± 3.14	15.19 ± 2.08	16.62 ± 2.33	P = 0.004
	HP	12.55 ± 2,64	14.79 ± 3.74	11.53 ± 2.65	13.68 ± 2.91	P = 0.027
	CP	12.44 ± 2.63	13.63 ± 3.01	11.12 ± 3.22	12.59 ± 3.02	P = 0.161

SB: Sodium bicarbonate, HP: Hydrogen peroxide, CP: Carbamide peroxide.

Between-group comparison of the L* parameter (Table 2) with Tukey's test revealed no significant difference between the groups at T1 or T2 (P > 0.05). At T3 and T4, SB had significant differences with HP and CP groups (P < 0.05).

Table 2- Between-group comparisons of the mean L*, a*, and b* parameters using Tukey's test

			P values at different time points			
			T_1	T_2	T_3	T_4
L*	SB	HP	P = 0.88	P = 0.922	P = 0.025	P = 0.026
		CP	P = 0.287	P = 0.357	P = 0. 250	P = 0. 003
	HP	SB	P = 0.880	P = 0.922	P = 0.025	P = 0.026
		CP	P = 0.551	P = 0.58	P = 0.519	P = 0. 683
	CP	HP	P = 0.551	P = 0.580	P = 0.519	P = 0. 683
		SB	P = 0.287	P = 0.357	P = 0.250	P = 0.003
a*	SB	HP	P = 0.826	P = 0.916	P < 0.0001	P < 0.0001
		CP	P = 0.791	P = 0.458	P < 0.0001	P < 0.0001
	HP	SB	P = 0.826	P = 0.916	P < 0.0001	P < 0.0001
		CP	P = 0.998	P = 0.793	P = 0.893	P = 0.873
	CP	HP	P = 0.998	P = 0.703	P < 0.0001	P = 0.873
		SB	P = 0.791	P = 0.458	P < 0.0001	P < 0.0001
b*	SB	HP	P = 0.998	P = 0.996	P = 0.002	P = 0.016
		CP	P = 0.999	P = 0.952	P = 0.0001	P = 0.001
	HP	SB	P = 0.998	P = 0.996	P = 0.002	P = 0.016
		CP	P = 0.995	P = 0.601	P = 0.911	P = 0.535
	CP	HP	P = 0.995	P = 0.601	P = 0.911	P = 0.535
		SB	P = 0.999	P = 0.652	P = 0.0001	P =0.0001

SB: Sodium bicarbonate, HP: Hydrogen peroxide, CP: Carbamide peroxide

The "a*" parameter:

Table 1 illustrates the mean a* parameter in the three groups at different time points. Within-group comparison in the SB group revealed significant differences between T1 with the other three time points (P < 0.001). In the HP group, significant differences were noted between T1 and T2, and also T2 and T3 (P < 0.001). In the CP group, significant differences were noted between T1 and T2, and also between T2 and T3 (P < 0.001).

Between-group comparisons of the mean a* parameter are presented in Table 2. No significant difference was noted between the groups at T1 or T2 (P > 0.05). However, at T3 and T4, SB had significant differences with HP and CP (P < 0.05).

The b* parameter:

Table 1 presents the mean b* parameter in the three groups at different time points. In the SB group, a significant difference was noted between T1 and T4 (P < 0.05). In the HP group, the difference between T2 and T3 was significant (P < 0.05). In the CP group, the difference in this respect was not significant between different time points (P = 0.161).

Between-group comparisons of the mean b* parameter are presented in Table 2. No significant difference was noted between the groups in T1 or T2 (P > 0.05). At T3 and T4, however, SB had significant differences with HP and CP groups (P < 0.05).

The ΔE parameter:

Table 3 presents the mean ΔE in the three groups at different time points. In the SB group, a significant difference was noted between ΔE1 and ΔE3 (P < 0.05). In the HP group, no significant difference was noted in ΔE at different time points (P = 0.169). In the CP group, no significant difference was noted in ΔE at different time points (P = 0.919).

Between-group comparisons of the mean ΔE using Tukey's test are presented in Table 4. The three groups were not significantly different in ΔE1 and ΔE3 (P > 0.05). SB and HP had a significant difference in ΔE2 (P < 0.05).

Table 3- Mean ΔE in the three groups at different time points**.**

Group	ΔE_1	ΔE_2	ΔE_3	P value
SB	6.25 ± 3.19	4.62 ± 2.29	3.77 ± 2.24	P=0.019*
HP	6.64 ± 4.23	8.77 ± 5.28	5.7 ± 3.74	P=0.169
CP	6.39 ± 2.34	5.9 ± 2.67	6.25 ± 4.57	P=0.919

SEM results:

As shown in Figure 1, the unbleached enamel surface was not completely smooth. As is illustrated in Figures 1a and 2a, some pellicle, as well as surface porosities and irregularities are observed in various parts. The use of bleaching agents caused different changes in the enamel surface. Figure 1b (after bleaching) reveals that the pellicles were eliminated from the enamel surface and the depth of some enamel porosities increased after bleaching. Some new porosities and surface irregularities were also seen. In the HP group (Figure 2b), more porosities were seen with a regular pattern on the entire surface and the depth of enamel irregularities increased as well after bleaching. In the CP group (Figure 3b), a flake pattern was seen on the entire surface, and more distinct and deeper porosities were seen after bleaching compared with the other two groups.

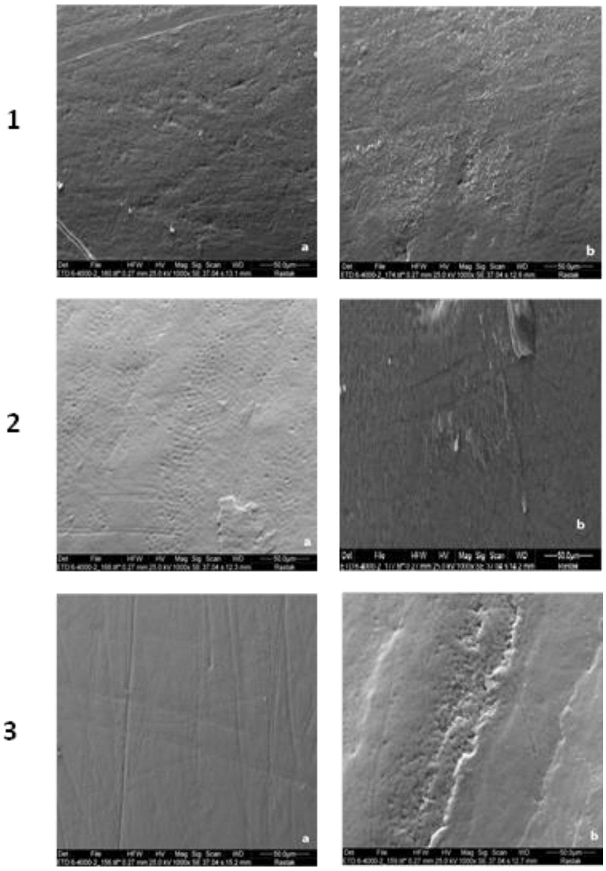

Figure 1: The enamel surfaces of tooth samples under scanning electron microscopy (SEM) at x1000 magnification. 1) Sodium bicarbonate group (a) before treatment and (b) after treatment; 2) Hydrogen peroxide group (a) before treatment and (b) after treatment; and 3) Carbamide peroxide group (a) before treatment and (b) after treatment

Discussion

The present study assessed the effect of SB on tooth discolouration and the enamel surface of tooth samples in vitro. The findings showed that applying SB 94% results in a significant colour change ($\Delta E > 3.5$) with no surface wear. However, the maximum bleaching effect belonged to HP ($\Delta E = 8.77$). On the other hand, the SB group showed minimal staining after re-staining ($\Delta E = 3.77$) compared with HP and CP groups.

The abrasive property of SB in tooth bleaching has been previously evaluated; however, its chemical bleaching effect has not been well studied. Collins [18] reported that SB has physical and chemical cleansing efficacy.

In general, tooth bleaching occurs as the result of an increase in the L* (lightness) parameter. High L* values indicate higher lightness while lower L* values indicate lower lightness. A reduction in L* parameter is not expected after tooth bleaching[19]. In our study, all three groups showed an increase in the L* parameter after bleaching. Sulieman et al.[20] (2004) evaluated different concentrations of HP with different frequencies of use and reported an increase in L* parameter in all groups, indicating optimal bleaching efficacy. Gerlach et al.[21] (2000) compared the clinical efficacy of bleaching strips containing 5.3% HP and bleaching systems containing 10%, 15%, and 20% HP. All groups showed an increase in the L* parameter after bleaching. Patel et al.[22] (2008) demonstrated a significant increase in ΔL^* in groups treated with CP 10% and 35% and HP 35% with halogen light.

In the CIE L*a*b* system, the color change is shown by ΔE[1]. Evidence shows that $0 < \Delta E < 1$ is not detectable by the observer. Values of $1 < \Delta E < 2$ may be detected by an experienced and skillful observer while values of $2 < \Delta E < 5$ are detectable by all observers. Values of $3.5 < \Delta E < 5$ indicate considerable color change and ΔE values > 5 indicate two different colours. [16] In this study, all groups showed significant color improvement ($\Delta E > 3.5$). Among the study groups, the bleaching efficacy of HP was higher than that of SB ($P < 0.05$). Also, the results showed that the re-staining of the SB group was lower than that of the other two groups and SB can prevent re-staining. Ahrari et al.[8] (2017) reported that all groups showed $\Delta E > 3.5$ after bleaching. A comparison of the groups revealed that a combination of 94% SB and 1.5% HP along with casein phosphopeptide amorphous calcium phosphate resulted in a maximum bleaching effect with an ΔE=23.8. However, no significant difference was noted in the bleaching efficacy of 94% SB paste alone and in combination with 1.5% HP. The low concentration of HP used in their study may explain its poor bleaching efficacy[8]. Meireles et al.[23] (2012) reported that all groups showed $\Delta E > 3.5$ after bleaching; CP 37% showed ΔE =10.1 and with an increase in the concentration of CP, its bleaching efficacy increased as well. Zakavi et al.[19] (2017) observed $\Delta E > 3.5$ after bleaching in all groups. A comparison of the groups revealed that a combination of at-home and in-office bleaching using CP 15% and HP 40% was the most effective tooth-bleaching method with $\Delta E = 9.94$.

The current results showed that SB can chemically cause significant bleaching of teeth with no abrasive effect on the tooth structure and can also prevent re-staining. This study was the first to assess the chemical efficacy of SB for tooth bleaching. To the best of the authors' knowledge, no previous study is available on this topic. However, some studies are available regarding the physical and abrasive properties of SB in toothpaste and chewing gums. [11, 14, 18, 24, 25] Kleber et al.[24] (1998) showed that toothpaste containing high concentrations of SB was more effective than toothpaste without SB in the elimination of internal staining. Collins [18] (2008) stated that SB serves as a chemical and mechanical cleansing agent and its mechanical activity is due to its abrasive property. However, it has low abrasiveness and an excellent cleansing effect, which is important in the elimination of stains and prevention of re-staining. Ghassemi et al. [14] (2012) reported that Arm & Hammer toothpaste containing 50% SB and 1% sodium carbonate peroxide, sodium fluoride, and tetrasodium pyrophosphate was effective for removal of extrinsic stains and tooth bleaching and also prevented re-staining. Moreover, they added that the mechanism of prevention of re-staining by SB can be chemical. Li [11] (2017) in a review study reported that SB is a suitable abrasive for bleaching toothpaste since it has relatively low abrasiveness and brings about clinically confirmed optimal bleaching results with maximal benefits and minimal complications. Also, they added that the abrasiveness of SB was relatively lower than that of conventional abrasives such as calcium carbonate and calcium pyrophosphate, and it also had antibacterial activity in high concentrations. [11]

In the present study, the enamel surface morphology was also evaluated before and after bleaching using SEM. The micrographs revealed that SB had fewer adverse effects on the enamel surface than HP and CP and caused fewer porosities. It can be explained by the fact that low pH can change the mineral content of enamel and dentin, and mineral loss can alter the enamel surface morphology. [26] Bleaching agents with an acidic pH can cause complications such as enamel demineralization and surface porosities. [17] Low pH and high acidic concentration result in maximum porosities while high pH and low acidity result in minimal porosities. [27] Since bleaching agents are in contact with the teeth for several hours, they must have a relatively neutral pH to minimize damage to the tooth structure. [28] The current study showed that SB, with a higher pH than HP and CP, caused fewer alterations in the enamel surface. Ito and Momoi [5] (2011) performed SEM analysis and reported significantly shallower enamel surface erosion in the use of SB and HP 30% compared with in-office bleaching with HP. Higher pH of SB was responsible for this result [5], which was in agreement with our findings. Sasaki et al.[2] (2009) discussed that enamel surface porosities after bleaching with CP 10% and HP 7.5% are due to the presence of urea and oxygen as the products of bleaching agent oxidation. Urea denatures the proteins present in the organic part of the tooth structure and alters the enamel surface morphology.

Future clinical studies are required to confirm the efficacy of SB paste in bleaching trays for use in the clinical setting. Also, different concentrations of SB should be evaluated to find the concentration with maximum efficacy. Moreover, further investigations are required on the chemical composition of SB and its chemical mechanism of bleaching.

Conclusion

Within the limitations of this study, the results showed that SB can chemically resolve tooth discoloration and prevent re-staining. Considering its low abrasiveness, optimal safety, low cost, antimicrobial activity, and availability, it seems to be ideal for use at home.

Conflict of Interest

No Conflict of Interest Declared ■

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