Bleaching using 30% hydrogen peroxide and sodium hydrogen carbonate

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This study investigated the bleaching efficacy of a mixture of sodium hydrogen carbonate (NaHCO₃) and 30% hydrogen peroxide (H₂O₂), the latter being an active ingredient in in-office bleaching products. A commercially available 35% H₂O₂-based in-office bleaching product was used as a control and for comparison. Enamel surfaces after bleaching were evaluated for post-bleaching color change, Vickers hardness, surface roughness, erosion depth, and surface morphology (SEM images). The bleaching efficacy of 30%H₂O₂-NaHCO₃ was comparable to that of control, and favorable results over the control were obtained after bleaching with 30%H₂O₂-NaHCO₃, lower increase in surface roughness, smaller erosion depth, and reduced extent of enamel erosion based on SEM images. These results were obtained because an addition of NaHCO₃ to H₂O₂ changed the initially low pH to a higher one.

Keywords: Bleaching, Hydrogen peroxide, Sodium hydrogen carbonate, Human extracted teeth

INTRODUCTION

Chemical agents such as hydrogen peroxide (H₂O₂), carbamide peroxide [CO(NH₂)₂·H₂O₂], and sodium perborate (NaBO₃·4H₂O) are commonly used to bleach teeth. Both carbamide peroxide and sodium perborate react with water to produce H₂O₂, which is the main agent responsible for the bleaching effect. Bleaching works by the oxidation of polymeric organic substances (pigments) that cause tooth discoloration. The free radicals generated from H₂O₂ disrupt the double bonds of the organic pigments, thereby altering the pigments into achromatic low-molecular substances¹,².

Amid the growing demand for white teeth, there is also a growing concern that the low pH of bleaching agents might result in enamel decalcification³,⁴. In Japan, the pH values of bleaching products currently available on the market are comparatively low: pH 3 to 6 for in-office bleaching. In the US, pH of some products are adjusted to over 7.5 and for dentifrices, baking soda [sodium hydrogen carbonate (NaHCO₃)] was added to H₂O₂ at a low concentration⁵,⁶ and bleaching efficacy was reported⁷.

In this study, we mixed sodium hydrogen carbonate (NaHCO₃), which is weakly alkaline and is used in cooking and antacid preparations, with commercially available highly concentrated 30% H₂O₂ (superoxol). The latter is a commonly used in-office bleaching agent. Due to the addition of NaHCO₃, the experimental bleaching agent 30%H₂O₂-NaHCO₃ was adjusted to a higher pH. Its bleaching efficacy and influences on enamel were then evaluated and compared against those of a commercial bleaching product.

MATERIALS AND METHODS

Specimen bleaching

Five human molars, extracted for orthodontic or periodontal reasons and stored frozen, were used in this study. The buccal and lingual enamel surfaces were polished with a brush and a polishing paste (Pressage, Shofu Inc., Kyoto, Japan) to remove stains. The teeth were then cut into two halves mesiodistally in the middle of the crown.

To minimize individual differences among the specimens, 30%H₂O₂-NaHCO₃ and a 35% hydrogen peroxide (H₂O₂)-based in-office bleaching product (OFP; Shofu Hi Lite, Shofu Inc., Kyoto, Japan) were applied on two halves of the same tooth. Half of the specimens (n=5) were bleached using 30%H₂O₂-NaHCO₃, while the other half (n=5) were bleached using OFP. Except for the enamel surfaces that were being bleached, the specimens were embedded in a mold with all the other surfaces covered with a modeling compound to avoid any contact between the bleaching agent and surrounding compound.

For OFP, bleaching was carried out according to the recommended procedure by mixing the powder and liquid for 30 seconds, followed by applying the mixture to the enamel surface for 5 minutes. After 5 minutes, OFP mixture was irradiated with a halogen curing light (Optilux 501, Demetron/Kerr, Orange, CA, USA) for 3 minutes. After being kept undisturbed for 1 minute, the bleaching agent was removed. The enamel surface was wiped with a cotton swab, and the bleached surface was washed with water. This procedure, as per the manufacturer’s instruction for this product, was repeated three times for each bleaching routine, the latter being carried out once per day, for a duration of 6 days. Colorimetric measurement

During the 6-day bleaching regime, all specimens were stored at 37°C temperature and 100% humidity. On a daily basis from day 1 to day 6, colorimetric measurement was performed three times before and after bleaching.

References


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using a spectrophotometer (Spectro Color Meter SE-2000, Nippon Denshoku Industries Co., Ltd., Tokyo, Japan). Corresponding \( L^*, a^*, \text{ and } b^* \) values were measured on a gray background with brightness \( V \), and color difference \( (\Delta E^{*ab}) \) before and after bleaching was thereby calculated.

**Vickers hardness measurements before and after in-office bleaching**

Four bovine teeth were used for the Vickers hardness test in this study. Labial enamel surfaces were ground flat with a successive use of waterproof abrasive papers (#180–#1500). A labial-lingual cut was made in the middle of the ground surface using a micro cutter. To minimize individual differences among the specimens, 30% H\(_2\)O\(_2\)-NaHCO\(_3\) and OFP were applied to two halves of the same tooth. Bleaching was also performed in the same manner as that described above for extracted human teeth.

Vickers hardness was measured using a hardness tester (Hardness Tester MVK-E, Akashi Corp., Kanagawa, Japan) to assess the effect of 30% H\(_2\)O\(_2\)-NaHCO\(_3\) bleaching on surface hardness. Hardness measurements were made at 10 points per specimen and were carried out both before and after bleaching at a load of 4.9 N for 30 seconds.

**Surface roughness measurements before and after in-office bleaching**

Four bovine teeth were used for surface roughness measurements in this study. Specimen preparation and bleaching procedures were the same as those employed above for bovine enamel for Vickers hardness measurement.

Surface roughness (Ra, \( \mu m \)) was measured using a surface profilometer (Surfcom 590A, Tokyo Seimitsu Co., Ltd., Tokyo, Japan), where measurement length was 3 mm and cut-off value was 0.8 mm. Incidentally, 3 mm was the maximum measurement length available. Measurements were performed three times per specimen before and after bleaching. Increase in surface roughness was expressed as an increase ratio, whereby roughness (Ra) value after bleaching was divided by the roughness (Ra) value before bleaching.

**Surface erosion evaluation before and after in-office bleaching**

Five bovine teeth were used to evaluate the effect of 30% H\(_2\)O\(_2\)-NaHCO\(_3\) bleaching on surface erosion in this study. Labial enamel surfaces were ground flat with a successive use of waterproof abrasive papers. A groove of 10 mm length and approximately 1 mm width was created mesiodistally in the middle of the ground bovine enamel surface. Using a light-cured bonding material (Clearfil Megabond, Kuraray Medical Inc., Tokyo, Japan), the groove was filled with a resin composite (BEAUTIFIL Flow F10, Shade A3, Shofu Inc., Kyoto, Japan), and then the whole surface was polished with a series of waterproof abrasive papers (#180–#1500). Using a cutter knife, a reference line as a marker was drawn in the middle of the resin composite surface, the latter being regarded as the reference plane of non-erosive material. Bleaching procedures were the same as those employed for bovine enamel for Vickers hardness measurement, but bleaching time was increased to 10 days.

Erosion depths (\( \mu m \)) were measured using the surface profilometer. Before and after bleaching, the surface roughness of bovine enamel across the reference resin composite plane was measured with a measurement length of 4 mm and a cut-off value of 0.8 mm. On each of the roughness profiles obtained for enamel and resin composite, five highest points and five lowest points were selected to make two medium lines. The difference thereof between these two lines was defined as erosion depth in \( \mu m \). Five specimens were evaluated, and each sample was measured at three different locations (Fig. 1).

**Surface morphology evaluation by SEM**

Bovine tooth specimens which had already been subjected to surface roughness test were cut using a micro cutter. Using a Quick Auto Coater (SC-701AT, Sanyu Denshi Co. Ltd., Tokyo, Japan), the enamel surfaces were vapor-deposited with a gold coating of 250 nm. These coated enamel surfaces were then observed using SEM (ERA-8000, Elionix Inc., Tokyo, Japan) at \( \times 1,500 \) magnification and an accelerating voltage of 10 kV.

**Statistical analysis**

Statistical analysis was performed using two-way ANOVA, and multiple comparisons were performed using Duncan’s post hoc test (\( \alpha=0.01, \alpha=0.05 \)). While, \( \text{t-test} (\alpha=0.05) \) was used for Vickers hardness, surface roughness, and surface erosion.
RESULTS

Bleaching effect of 30%H₂O₂-NaHCO₃ on extracted human teeth

Post-bleaching color change results are shown in Table 1, and their statistical analysis is shown in Table 2. From day 1 to day 6, ΔE*a*b increased after bleaching with both 30%H₂O₂-NaHCO₃ and OFP. Throughout the 6-day bleaching regime, no significant differences were found between 30%H₂O₂-NaHCO₃ and OFP.

Vickers hardness of bovine enamel before and after in-office bleaching

Results are shown in Fig. 2. After bleaching, mean Vickers hardness decreased from 246 to 238 for 30%H₂O₂-NaHCO₃ and from 258 to 245 for OFP. A slight reduction in hardness was found for both bleaching agents, but the difference was not statistically significant (p>0.05).

Surface roughness of bovine enamel before and after in-office bleaching

Results are shown in Fig. 3. After bleaching, the mean increase ratio in surface roughness for 30%H₂O₂-NaHCO₃ was 0.98±0.26 whereas that for OFP was 1.25±0.37. Surface roughness increased after bleaching with OFP. A statistically significant difference (p<0.05) in increase ratio of surface roughness was found between these two bleaching agents.

Surface erosion of bovine enamel after in-office bleaching

Results are shown in Fig. 4. After bleaching, the mean erosion depth was 0.27±0.13 µm for 30%H₂O₂-NaHCO₃, and 0.85±0.37 µm for OFP. Statistical analysis revealed that erosion depth was significantly smaller (p<0.05) after bleaching with 30% H₂O₂-NaHCO₃.

Table 1 Mean±SD values of color difference (ΔE*a*b) after bleaching

<table>
<thead>
<tr>
<th>Day</th>
<th>30%H₂O₂-NaHCO₃</th>
<th>35%H₂O₂ based office bleaching product (OFP)</th>
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<td>Day 1</td>
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<td>7.4 (2.9)</td>
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<td>Day 6</td>
<td>7.7 (3.8)</td>
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Table 2 Statistical analysis of color difference results in Table 1

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N: 30% H₂O₂-NaHCO₃
Hi: 35% H₂O₂-based in-office bleaching product (OFP)
*: p<0.05, **: p<0.01
Surface morphology of bovine enamel after in-office bleaching

SEM images are shown in Fig. 5. Scratches formed during polishing were found on the bovine enamel surface after bleaching with 30%H₂O₂-NaHCO₃ (Fig. 5a), but no such scratches were observed after bleaching with OFP (Fig. 5b). In the latter case, more convex-concave surface images were observed.

DISCUSSION

The sodium bicarbonate or baking soda used in this experiment, i.e., NaHCO₃, was a slightly alkaline white powder with an approximate pH value of 8. It is a substance found in nature and is used in myriad ways. Apart from its uses in baking, cooking and as a food additive, it is also widely used in laundry detergents, deodorants, toothpastes, and oral rinses as an environmentally friendly cleaning substance.

Previously, we reported that when a weakly alkaline NaHCO₃ was added to 3% H₂O₂, the pH level of resultant H₂O₂-NaHCO₃ mixture was changed from 3.8 to 6.1. When exposed to light, heat and alkaline environment, H₂O₂ reacts with metal ions and breaks down readily to form •OH (hydroxyl radicals), •H, HOO• (perhydroxyl radical), and O₂•⁻ (superoxide anion radical). The •OH is the strongest oxidant of the oxy-radicals, and it oxidizes and disrupts unsaturated double bonds. Therefore, it was suggested that the •OH degrades the pigments (polymeric organic substances) into achromic low-molecular substances.

In a study by Kashima-Tanaka et al.¹⁰, the amount
of free radicals and/or active oxygen generated upon exposure of H$_2$O$_2$ to light changed according to the concentration of H$_2$O$_2$ and light irradiation time. However, apart from dependency on light, heat and metals, the decomposition of H$_2$O$_2$ to form strongly oxidative •OH is also catalyzed by an alkaline environment as opposed to an acidic environment$^{11-14}$. Indeed, we anticipated that an alkaline environment is a more critical factor to ensuring a greater bleaching efficacy, as explained in Fig. 6 through the degradation of pigments —via the bleaching effect of H$_2$O$_2$— in an alkaline environment. Under alkaline conditions, H$_2$O$_2$ dissociates and undergoes an ionic reaction to form •OH and •HOO. These radicals are, by themselves, the active species in the bleaching process, thereby degrading the high-molecular pigments into achromic low-molecular substances$^1$. 

In the present study, the color change in extracted human teeth after bleaching with H$_2$O$_2$-NaHCO$_3$ indicated that with 30% H$_2$O$_2$, a bleaching efficacy equivalent to that of a commercial in-office bleaching product could be achieved (Tables 1 and 2). Moreover, the availability of an alkaline environment, via the addition of NaHCO$_3$, is expected to catalyze the decomposition of H$_2$O$_2$ to form strongly oxidative •OH —as shown in our previous study using H$_2$O$_2$ alone versus a mixture of H$_2$O$_2$ and NaHCO$_3$ on egg shells$^8$. 

On the effect of in-office bleaching on the microhardness of human enamel, it has been reported that treatment with 30% hydrogen peroxide reduced the microhardness of both enamel and dentin$^{15,16}$. However, treatment with sodium perborate mixed with hydrogen peroxide did not alter the microhardness of either enamel or dentin$^{19}$. 

In the present study, a slight reduction in bovine enamel hardness was observed after bleaching with both 30%H$_2$O$_2$-NaHCO$_3$ and OFP. Nonetheless, no statistically significant difference in hardness before and after bleaching were found for both bleaching agents. After bleaching with 30%H$_2$O$_2$-NaHCO$_3$, there was hardly any change in surface roughness. However, bleaching with OFP showed significant increase in roughness. This could be explained by the higher pH level of 30%H$_2$O$_2$-NaHCO$_3$ versus that of OFP. 

On the effects of pH level on enamel decalcification, Nishiguchi et al.$^{17}$ reported that enamel decalcification was observed at just 1 minute after immersion in a strongly acidic soft drink with a pH level of 2.3 to 4.9. In another study, Ernst et al.$^{19}$ reported that some bleaching agents caused slight surface morphological alterations whereas exposure to 37% phosphoric acid resulted in severe alterations. Similarly in the present study, Figs. 5a and 5b showed that the more alkaline 30%H$_2$O$_2$-NaHCO$_3$ (pH 6.1) caused less pronounced surface erosion on bovine enamel than the more acidic 35% H$_2$O$_2$. After bleaching with 30%H$_2$O$_2$-NaHCO$_3$, scratches caused by polishing were still clearly visible on the enamel surface. However, these scratches were not seen after bleaching with OFP. The latter’s low pH caused the surface scratches to be eroded away and even created convex-concave undulations on the surface.

In the clinical situation, tooth surfaces are protected by the acquired enamel pellicle due to the wash-out and acid-buffering effects of saliva. Therefore, post-bleached decalcified enamel would undergo recalcification in the presence of saliva$^{19-22}$. In healthy patients with normal salivary secretion, it could be assumed that bleaching would have no adverse effects on the tooth structure. However, for patients with reduced salivary secretion due to aging, systemic diseases or medication, findings of this study showed that it is important to consider using a higher-pH bleaching agent to avoid tooth erosion.

**CONCLUSIONS**

Within the limitations of the current study, the following conclusions were drawn: 
1. 30%H$_2$O$_2$-NaHCO$_3$ demonstrated a bleaching
efficacy equivalent to that of a 35% H2O2-based in-office bleaching product (OFP), in a higher-pH environment.

2. Increasing ratio of surface roughness and erosion depth after bleaching were significantly smaller in 30% H2O2-NaHCO3 as compared to OFP. This could well be explained by the higher pH of 30% H2O2-NaHCO3 as opposed to the lower pH of OFP.

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