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The Erosion Properties of Chlorine Dioxide and Hydrogen Peroxide on Bovine Teeth

Research Article

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Abstract

Objectives: The aim of this study was to assess the erosion potential of chlorine dioxide and hydrogen peroxide on bovine teeth.

Methods: Sixty bovine crowns were ground and polished to give flat surfaces. The crowns were subjected to heavy staining cycles then equally divided into 3 treatment groups; chlorine dioxide (ClO_2), hydrogen peroxide (H_2O_2), and deionised water (H_2O). Specimens in each group were immersed in 150 ml of the treatment for seven 2 min cycle in addition to an extra 30 min cycle. Specimens were gently dried after each 2 min cycle to take quantitative light-induced fluorescence (QLF) images while non- contact light profilometry (NCLP) scans were performed at the end of the seven 2 min and the extra 30 min cycles.

Results: ClO_2 specimens showed a significant increase in %ΔF only after the first 2 min cycle ($p < 0.05$); however, a significant increase in %ΔF within H_2O_2 specimens was found at the end of the seven recommended treatment cycles ($p < 0.05$).

Conclusion: Chlorine dioxide does cause enamel erosion but to a lesser extent than that caused by hydrogen peroxide.

Keywords: Bovine enamel; Erosion; QLF; Fluorescence; NCLP; Mean step height

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Introduction

Tooth discolouration is a common phenomenon that occurs due to extrinsic and/or intrinsic staining. The number of tooth whitening agents is on the increase to compensate for the increasing demand among a large number of people wanting whiter teeth. Peroxide bleaching, mainly hydrogen peroxide, is the commonly practised technique for whitening discoloured teeth. The safety, effectiveness, and various side effects of those products on intraoral structures have been widely investigated. Some of their associated and commonly reported potential side effects are erosion and porosity [1,2]. Low pH created by bleaching agents subjects teeth and oral tissues to an acidic environment for a period of time that could be considered sufficient to cause such side effects [3].

Investigations on the effects of pH on dental enamel suggested that low pH and high acid concentrations can cause enamel erosion [4]. In addition, possible alterations in the enamel organic matrix promoted by nonspecific and potentially reactive free radicals might result in decreased fracture toughness [3]. Chlorine dioxide tooth whitening* (Frontier Pharmaceutical Incorporation, New York, USA) has been considered as a 'safer' method for whitening teeth in shorter periods thereby avoiding the adverse effects usually associated with the use of peroxides [5]. Chlorine dioxide was first used in the form of Labarraque solution for bleaching non - vital teeth [6]. Currently, it is been used by non - dental establishments to whiten teeth.

Currently there is little in the literature to support the use of chlorine dioxide as a tooth whitening agent or to prove its safety for use on dental hard tissues. Only one article discussed the dangers of chlorine dioxide as a bleaching material and its subsequent side effects [7]. In the UK, a legal action was taken against a man who practised the use of chlorine dioxide and caused detrimental effects to the dentition of the 23 - year - old Stephanie Ramezan [8].

Dioxiwhite™ is marketed in the UK as tooth whitening agent. Its gel utilises chlorine dioxide as its active tooth whitening ingredient. Chlorine dioxide has strong oxidising properties and whitens teeth in a similar way to that reported with 35% hydrogen peroxide [9].

The main aim of this study was to assess, in vitro, whether chlorine dioxide has a dental erosion potential using quantitative light - induced fluorescence (QLF) and non - contact light profilometry (NCLP) in the assessment of dental erosion.

Materials and Methods

Sixty extracted bovine incisors devoid of intrinsic stains, cracks, and fractures were selected and had their roots separated. All crowns were ground and polished using 350 - grit and 1200 - grit SiC sandpaper (Wet and Dry Sandpaper, 151 Products Limited, Manchester, UK) under copious amounts of water until flat enamel surfaces were obtained. Each crown was then embedded in green impression compound material (Kerr Dental, USA) making approximately 2.5 x 2.5 x 1.8 cm blocks. These set of crowns were then subjected to the following extrinsic staining cycles:

The 60 blocks were attached to a total of 3 beakers containing staining fluids in the following sequence: a. 150 ml of artificial saliva (Table 1), b. 150 ml of chlorehexidine mouthwash (Chlorhexidine Gluconate 0.2%. v/w, ECOLAB, England) and c. 150 ml of tea (PG tips, UK). Artificial saliva was prepared in the laboratory and the tea solution was prepared by brewing 4 tea bags in boiling water and allowing the infusion to cool over a period of 30 min. The blocks were gently agitated (150 rpm, Bibby Sterilin, UK) for 2 min cycles in each staining solution until the stain intensity appeared unchanged on visual inspection (a total of 10 staining cycles). Subsequently, specimens were left overnight in deionised water allowing for stain maturation [10].

The blocks were then equally assigned to the following three experimental groups (n = 20 per group):

1. Chlorine dioxide (Frontier Pharmaceutical Incorporation, NY, USA).
2. Hydrogen peroxide (Fisher Scientific Ltd, UK) (positive control).
3. Deionised water (negative control).

- Windows of 3 x 3 mm were created on each specimen using acid - resistant clear nail varnish (Maxfactor®, Procter and Gamble, Weybridge, UK) and allowed to bench - dry overnight.
- Baseline QLF™ images and NCLP scans were performed for all specimens.
- The pH of the three experimental materials was tested in triplicate and a mean pH value obtained.

Experimental Groups

Group 1: Chlorine dioxide (ClO_2)

The mounted crowns were subjected to a whitening regimen according to the manufacturer recommendations. They were bleached by the application of a 2 - 3 mm thickness of the gel and then exposed to an activating light source for 2 min. Seven treatment cycles were performed with an additional eighth cycle where ClO_2 was left on the specimens for 30 min. After each cycle, specimens were washed with deionised water spray and a gentle air jet drying then left to further dry for 15 min.

Group 2: Hydrogen peroxide (H_2O_2)

Specimens in this group were treated with 35% H_2O_2 at room temperature (21 ± 2°C). They were completely covered by the solution (150 ml) for seven, 2 min cycles in addition to the extra 30 min cycle. After each cycle, specimens were removed, rinsed with deionised water spray, dried with a gentle air jet and left to further dry for 15 min.

Table 1. Composition of artificial saliva

Methyle- p-hydroxybenzoate	2.00g/l
Na Carboxymethylecellulose	10.0g/l
$MgCl2.6H_2O$	0.29mM
$CaCl2.2H_2O$	1.13mM
$K2HPO_4$	2.40mM
KCL	8.38mM
F	0.05ppm
pH	7.2

Group 3: Deionised water (H_2O)

Specimens were immersed in deionised water (150 ml) following the same regimen for the two bleaching agents. After each cycle, they were gently air jet dried then left to further bench - dry for 15 min.

After each treatment cycle, QLF images were taken for all specimens. NCLP scans were performed at the end of cycle 7 and the extra 30 min cycle.

Statistical Analysis

The results were analysed using SPSS statistical package (Version 15, SPSS Inc., Chicago, USA). Changes with values of $p < 0.05$ or less were considered statistically significant. Continuous variables were expressed as mean ± SD. *Post hoc* Tamhane test was performed to identify significantly different group means when ANOVA test was significant [11]. Paired *t* - test was carried out between baseline and each subsequent cycle.

Results

pH

The data in Figure 1 shows the pH values of the 3 experimental materials. At baseline the pH values of ClO_2 and H_2O_2 in conjunction with H_2O were 3.35, 2.10, and 6.40, respectively.

Quantitative Light - Induced Fluorescence Data

There was no significant difference in the change in mean fluorescence loss (% fluorescence loss) results when ClO_2 and H_2O_2 were compared after the first three (C1 - C3) treatment cycles ($p > 0.05$). However, the next two cycles (C4 and C5) showed a significant increase in % fluorescence loss between the two treatments ($p < 0.05$). This increase in % fluorescence loss became highly significant as the treatment application continued for the rest of recommended cycles and the further 30 min cycle ($p < 0.001$) (Figure 2).

In the ClO_2 group, the within group analysis showed a significant increase in % fluorescence loss from baseline to cycle 1 ($p < 0.05$). The subsequent cycles (C2 - C7) and the 30 min cycle, however, showed no significant difference in % fluorescence loss ($p > 0.05$).

In contrast, H_2O_2 specimens showed no significant difference ($p > 0.05$) in % fluorescence loss levels after the first six treatment cycles after which % fluorescence loss levels were significantly different ($p = 0.001$). However, this difference in % fluorescence loss was less significant ($p = 0.05$) when the application extended for the extra 30 min cycle.

Non - Contact Light Profilometry Data

Specimens in both treatment groups showed a highly statistical significant increase in the mean step height after the recommended 7 and the extra 30 min cycles ($p = 0.001$) (Figure 3). However, the mean step height within the H_2O_2 group was significantly greater than that for the ClO_2 specimens ($p = 0.000$).

Discussion

Despite the controversy regarding their adverse effects; pulpal irritation [12,13], micro - leakage of restorations [14], reduced bond strength of resin materials [15,16] as well as external root resorption on teeth surface [17], peroxide bleaching remains the most commonly practised technique for whitening discoloured teeth. The low pH of these bleaching materials, manifesting itself in surface structure changes, is a major concern [18-20].

Enamel erosion occurs below the critical pH [21]. In the current study, the tested bleaching materials had pH values below the critical pH (2.10 and 3.35 for H_2O_2 and ClO_2, respectively). However, ClO_2 had a slightly higher pH indicating less erosive tendency than that of H_2O_2.

Additionally, the intra- oral temperature was reported to be a factor that might affect the pH [22]. This study was carried out at room temperature which varied particularly on a warm or a cool day and further studies are needed to investigate this effect. Despite their whitening effect, peroxide bleaching side effects cannot be avoided either during or after the bleaching procedure. Depending on what concentration used, either high or low and the period of exposure, enamel demineralisation is inevitable [23]. H_2O_2 is capable of changing the apatite structure and the PO^{3-}_4 is replaced with diperoxo (H_4O_4) ligands which are believed to be weaker [24,25].

Chlorine dioxide whitening gel used in the this study had a concentration similar to 35% hydrogen peroxide and, for the purpose of comparison of their effect, similar application regimen was used. QLF results showed that by the end of the seven 2 min application cycles, there was only 0.8% fluorescence loss as compared with fluorescence loss of 3.7% within the H_2O_2 group. Extending the application period to 30 min did not result in further increase in % fluorescence loss among ClO_2 specimens while those treated with H_2O_2 had a slight increase in fluorescence loss by 1.4% (Figure 2). The less mineral loss from ClO_2 specimens, expressed by the reduction in % fluorescence loss values, could be the result of the post - cycles air jet drying used to partly remove the gel from the treated surfaces and to partially dry them. Despite been carefully performed, using gentle air jet was able to remove demineralised surface layers because of their low mechanical properties. Consequently and after each cycle, this continuously may have caused the removal of the highly demineralised surface layer responsible for the reduced fluorescence loss and the exposure of the more mineralised subsurface layers. On the other hand, the increased % fluorescence loss among the H_2O_2 specimens could be the result of the dissociated hydrogen ions causing etching - like effect on the enamel surfaces as follows:

- Hydrogen peroxide dissociates into water and oxygen

  $$2H_2O_2 \longrightarrow 2H_2O + O_2$$

- Water then ionises to make four hydrogen and 2 hydroxyl ions

  $$2H_2O \longrightarrow 2H^+ + 2OH^-$$

Figure 1. Mean pH values for each of the experimental materials (ClO_2= Chlorine dioxide, H_2O_2= Hydrogen peroxide, H_2O= Deionised water)

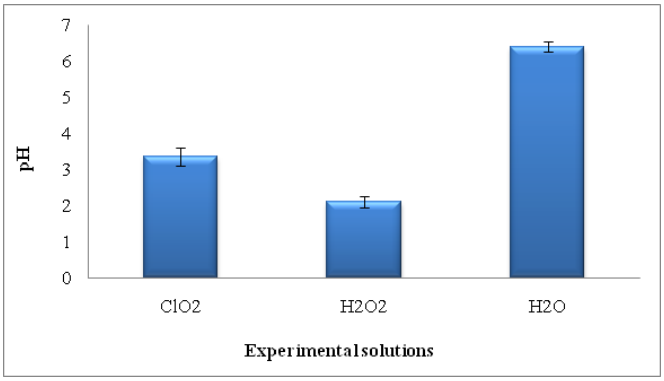


Figure 2. Diagram illustrating mean fluorescence loss (%ΔF) for the three experimental groups during each cycle: C1- C7 = recommended manufacturer cycles, C8 = extra 30 min cycle (* p < 0.05, ** p = 0.001). (ClO_2= chlorine dioxide, H_2O_2= Hydrogen peroxide, H_2O= Deionised water)

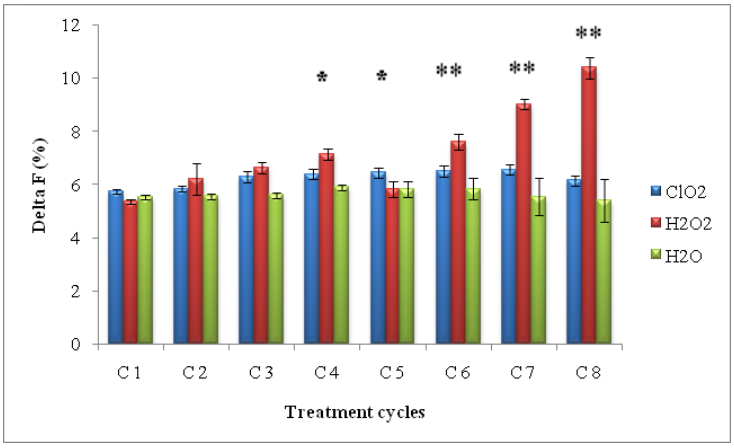
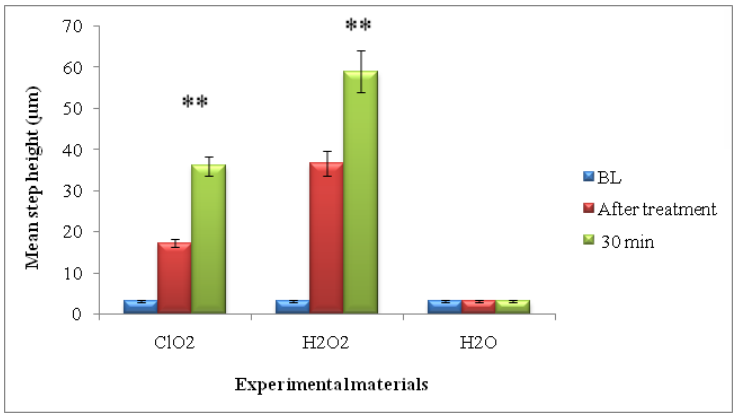


Figure 3. Diagram illustrating the mean step height at baseline (BL); after treatment (cycle 7); and after 30 min cycle (asterisks; p < 0.000). (ClO_2= chlorine dioxide, H_2O_2= Hydrogen peroxide, H_2O= Deionised water)



The effect of direct attack by those H^+ ions is to combine with the carbonate and / or phosphate releasing all of the ions from that region of the enamel crystal surface leading to direct surface etching [26].

NCLP results were similar to those of QLF as ClO_2 specimens had a mean surface loss of 17.2 µm at the end of cycle 7 as compared with 36.6 µm surface loss caused by H_2O_2 application. Surface loss increased after the 30 min application for both treatments reaching a mean of 36.0 µm and 58.9 µm for ClO_2 and H_2O_2 specimens, respectively (Figure 3). Enamel surfaces had to be ground and polished to facilitate NCLP scanning. Such process was not without an impact as it usually results in the removal of the potentially protective salivary pellicle known to act as a diffusion barrier by its selective permeable nature against destructive acids [27,28]. Furthermore, grinding results in the removal of the highly mineralised prismless enamel at the surface layer facilitating acid penetration to the deeper, less mineralised layers [29]. It would have been advantageous to test enamel without changing the morphology of teeth surface.

Another factor that may contribute to the profound erosion effect by the two treatments is the structural differences between human and bovine enamel. It has been mentioned that due to their higher porosity as compared with human enamel, bovine teeth are less resistant to acid diffusion and therefore, lesions tend to increase rapidly [30].

A further post - treatment recommended by the manufacturer was the application of the WhiteLasting™ Maintenance Gel containing calcium hydroxyapatite and fluoride (< 1% and > 0.5%, < 0.5% and > 0.1%, respectively). This step is to be repeated by the subject at home once or twice a day for the following 7 days. The present study was designed to observe the effect of chair-side application on enamel when bleaching materials were in contact with the tooth substance for a maximum period of 30 min. Therefore, this final step was not performed and whether it enhances remineralising bleached tooth surfaces or not requires further investigation.

Conclusion

Within the limitations of this study chlorine dioxide does cause enamel erosion but to a lesser extent than that caused by hydrogen peroxide. Therefore, its application for domestic or professional use should be with caution and under supervision.

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