

The pH of Tooth-Whitening Products

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A b s t r a c t

Tooth whitening products may be in contact with intraoral structures for several hours or they may be used daily to whiten the teeth. Consequently, these products should have a relatively neutral pH to minimize potential damage. This study measured the pH of 26 commercially available tooth-whitening products. The pH of the different whitening products ranged from 3.67 (highly acidic) to 11.13 (highly basic). The dentist-supervised home-bleaching products had a mean pH of 6.48 (range 5.66 to 7.35). The over-the-counter whitening products had a mean pH of 8.22 (range 5.09 to 11.13), and the whitening toothpastes had a mean pH of 6.83 (range 4.22 to 8.35). The 3 in-office bleaching products had a pH between 3.67 and 6.53. One-way ANOVA showed that there was a significant difference between the 4 product categories. The most basic pH of all the products tested was 11.13 for the whitening gel of Natural White-Rapid White. The most acidic pH of all products tested was 3.67 for Opalescence Xtra 35% hydrogen peroxide in-office bleach. The Least-Squares-Means test showed that the over-the-counter category had a pH significantly different from the other categories ($p < 0.05$).

MeSH Key Words: safety; tooth bleaching

© J Can Dent Assoc 2000; 66:421-6
This article has been peer reviewed.

Despite various potential toxicological side effects,¹⁻³ peroxides have been used for many years to treat periodontal diseases.^{4,5} Peroxides, usually in the form of hydrogen peroxide or carbamide peroxide, are also the active ingredient in most tooth-whitening agents. The safety, effectiveness and various side effects of these products on the intraoral structures have been investigated, and some products have been accepted by the American Dental Association for whitening teeth.^{1-3,6-25} However, some bleaching products have been reported to have a pH as low as 4.0, while others have been reported to have a pH of 7.5.²¹ It has been reported that the greater the peroxide concentration, the more acidic the pH of the bleaching product.²⁶ Some in-office bleaching products that contain 35% hydrogen peroxide may have a low pH.

Subjecting the teeth and oral tissues to a low or high pH for an extended period of time may cause adverse side effects. When the pH falls below 5.2, enamel demineralization²⁷ and root resorption have been reported.^{18,26} Recent research to investigate the effects of pH on enamel suggests that low pH and high acid concentrations cause enamel erosion.^{28,29}

Interestingly, adding small amounts of calcium to acidic solutions may decrease enamel loss by up to 50%.^{29,30}

Scanning electron microscopy studies^{6,16,19,20,31} have shown that a concentration of 10% carbamide peroxide alters enamel, causing surface dissolution and exposing a porous surface. In these studies, the untreated enamel was also smoother than the enamel treated with the bleaching agent. There was also a trend for the microhardness of enamel surfaces to initially decrease when the enamel was exposed to the bleaching agents.¹⁹ Haywood and others¹² presented contradicting evidence that there were no significant differences in surface texture between enamel treated with 10% carbamide peroxide and enamel stored in distilled water. Other side effects such as increased tooth sensitivity to temperature and gingival irritation have been reported when using a bleaching tray for vital bleaching.^{4,9-11,14,15}

Peroxides may also affect the properties of composite restorative materials, but it is not known if this effect is related to the peroxide concentration or the pH of the bleaching product. Cullen and others⁸ reported that the tensile strength of composite resins decreased when exposed to bleaching products containing 30% hydrogen peroxide, while the

composites treated with 10% carbamide peroxide showed no significant decrease in tensile strength. Cooley and Burger⁷ suggested that although exposure to 10% carbamide peroxide increased the surface roughness and hardness of composite resin materials, these differences were probably clinically insignificant.

Previous studies also suggest that the shear bond strength of composite resin to enamel is reduced after exposure to 35% hydrogen peroxide and 10% carbamide peroxide. This may be because the free peroxide and oxygen radicals released from the bleaching products interfere with the polymerization reaction, consequently reducing the bond strength. Alternatively, the decrease in bond strength may be due to changes in the mineral content of the enamel.^{17,21,22,31-33} However, the adverse effect on the bond strength appears to depend on the type of bonding system and may not be significant after 2 weeks.^{34,35}

The current study was undertaken to determine the pH of 26 commercially available tooth-whitening products. These products may be whitening toothpastes that are used on a daily basis or they may be products that are in contact with intraoral structures for prolonged periods of time in a bleaching tray. Consequently, the products should have a relatively neutral pH to minimize the potential for damage that could be caused by highly acidic or highly basic solutions. The hypothesis was that all the whitening products would have a similar and neutral pH of ~7.0.

Materials and Methods

Twenty-six commercially available tooth-whitening products were chosen based on availability in Canada and without prior knowledge of their pH (Tables 1-4). The products were divided into 4 categories: over-the-counter (OTC) products ($n = 3$), which are available in drugstores; in-office bleaching (IOB) products ($n = 3$), which are applied by a professional as an in-office treatment; dentist-supervised home-bleaching (DSHB) products ($n = 17$), which are dispensed by dentists to be used by patients at home; and 9 whitening toothpastes (TP), 6 of which came with the bleaching kits ($n = 9$). The pH was measured using a HANNA pH meter and an ORION semi-micro pH electrode (Orion Research Incorporated, Boston, MA). Some of the products required more than one step to complete the bleaching process, and hence each step was measured separately. The pH levels of Colgate Total toothpaste and 2 carbonated drinks (Pepsi and Coca Cola) were measured as a comparison to the various tooth-whitening products.

Table 1 Mean pH of 17 dentist-supervised home-bleaching products

Product Name	Manufacturer	Lot #	Mean pH ± SD
3M Zaris Professional Tooth Whitening System. 10% Carbamide Peroxide	3M Dental Products, St. Paul, MN	9C	6.33 ± 0.04
3M Zaris Professional Tooth Whitening System. 16% Carbamide Peroxide	3M Dental Products, St. Paul, MN	9E	6.23 ± 0.06
Colgate Platinum. Professional Whitening System. 10% Carbamide Peroxide	Colgate Oral Pharmaceuticals, Inc., Canton, MA	908022	5.66 ± 0.02
Colgate Platinum. Professional Whitening System. Overnight 10% Carbamide Peroxide	Colgate Oral Pharmaceuticals, Inc., Canton, MA	911001F	5.93 ± 0.08
Nupro Gold Tooth Whitening System. 10% Carbamide Peroxide	Dentsply International, York, PA	990823	5.97 ± 0.02
Nupro Gold Tooth Whitening System. 15% Carbamide Peroxide with Fluoride	Dentsply International, York, PA	990528	6.04 ± 0.02
Opalescence Tooth Whitening Gel. 10% Carbamide Peroxide	Ultradent Products, Inc., South Jordan, Utah	3LN1	6.79 ± 0.22
Perfecta 3/15 Dental Whitening System. 3% Hydrogen Peroxide Gel	Premier Dental Products Co., King of Prussia, PA	35071399	6.87 ± 0.02
Perfecta 3/15 Extra Strength 4.5% Hydrogen Peroxide Gel	Premier Dental Products Co., King of Prussia, PA	3X072899	6.93 ± 0.05
Perfecta Trio Step Whitening System. 11% Carbamide Peroxide	Premier Dental Products Co., King of Prussia, PA	TR 031099	7.35 ± 0.07
Perfecta Trio Step Whitening System. 13% Carbamide Peroxide	Premier Dental Products Co., King of Prussia, PA	TR 031099	7.14 ± 0.04
Perfecta Trio Step Whitening System. 16% Carbamide Peroxide	Premier Dental Products Co., King of Prussia, PA	TR 031099	6.83 ± 0.07
Quatro. Day White 2. 7.5% Hydrogen Peroxide	Discus Dental Inc., Culver City, CA	9HT-9HN	6.86 ± 0.68
Quatro. Nite White Excel 2. 16% Carbamide Peroxide	Discus Dental Inc., Culver City, CA	9GC-9GJ	6.80 ± 0.25
Rembrandt Bleaching Gel Plus. 10% Carbamide Peroxide	Den-Mat Corporation, Santa Maria, CA	567704	6.23 ± 0.01
Rembrandt Xtra Comfort, Extra Strength. 15% Carbamide Peroxide	Den-Mat Corporation, Santa Maria, CA	623015	6.11 ± 0.02
Rembrandt Xtra Comfort, Ultra Strength. 22% Carbamide Peroxide	Den-Mat Corporation, Santa Maria, CA	560011	6.15 ± 0.02
		Mean	6.48 ± 0.51

The pH meter was initially standardized using J.T. Baker buffered solutions of pH 4 and 7 (Mallinckrodt Baker, Inc., Phillipsburg, NJ) and was re-calibrated before testing each new product. All products were tested in triplicate to obtain mean pH values. The products were placed in disposable 3-ml Lancer analyser cups (Sherwood Medical Industries Inc., St. Louis, MO) and were stirred with the pH electrode to allow uniform contact with the electrode tip. Care was taken not to introduce air bubbles into the sample. The products were in contact with the pH electrode for 10 minutes at room temperature $21^{\circ}\text{C} \pm 2^{\circ}\text{C}$ to allow the pH value to stabilize (error max 0.11 for electrode drift). The electrode was thoroughly washed between samples using a stream of water to remove all traces of the previous sample. The electrode was then rinsed with distilled water and dried with a Kimwipes EX-L (Kimberly-Clark, Roswell, GA).

Results

The pH of all the tooth-whitening products tested ranged from 3.67 ± 0.06 (highly acidic) to 11.13 ± 0.18 (highly basic). The 17 DSHB products (Table 1) had a mean pH of 6.48 ± 0.51 (range 5.66 to 7.35). The 3 IOB products (Table 2) had a mean pH of 5.56 ± 1.64 (range 3.67 to 6.53). The OTC products (Table 3) had a mean pH of 8.22 ± 2.0 (range 5.09 to 11.13). The toothpastes (Table 4) had a mean pH of 6.83 ± 1.27 (range 4.22 to 8.35). The most basic pH of all products tested was in the whitening gel of Natural White-Rapid White, which had an average pH of 11.13 ± 0.18 (Table 3 and Fig. 1). One-way ANOVA using the product category as the factor showed that there was a significant difference between the categories ($F = 4.35$; $p = 0.0112$). The Least-Squares-Means test showed that the OTC category had a pH that was significantly different from all the other categories, but there were no significant differences between the IOB, TP and DSHB categories ($p = 0.05$). In comparison, the pH of a non-tooth-whitening toothpaste, Colgate Total, was relatively neutral at 7.39 ± 0.04 . The pH of Pepsi was 2.45 ± 0.02 , and the pH of Coca Cola was 2.49 ± 0.02 , but these were not included in the statistical analysis.

Discussion

The pH of the whitening products ranged from 3.67 to 11.13. This range was not close to a neutral pH of 7.0 and the hypothesis was rejected. This range in the pH went below 4.0, and was higher than the pH of 7.5 reported in 1992.²¹

When making judgments on the effects of highly acidic or highly basic solutions, it is important to consider the exposure time and how often the product is used. Most manufacturers recommend at least 1 to 2 hours of continuous wear for the

Table 2 Mean pH of 3 in-office bleaching products

Product Name	Manufacturer	Lot #	Mean pH \pm SD
Opalescence Quick. 35% Carbamide Peroxide	Ultradent Products, Inc., South Jordan, Utah	3GWN	6.53 ± 0.01
Opalescence Xtra. 35% Hydrogen Peroxide	Ultradent Products, Inc., South Jordan, Utah	3HWQ 3NNG 3PBT	3.67 ± 0.06
Rembrandt Quick Start Bleaching Gel Syringe Kit. 35% Carbamide Peroxide	Den-Mat Corporation, Santa Maria, CA	961034	6.48 ± 0.03
		Mean	5.56 ± 1.64

Table 3 Mean pH of 3 over-the-counter bleaching products

Product Name	Manufacturer	Lot #	Mean pH \pm SD
Natural White-Rapid White. Tooth Enamel Whitening System. Step2 Whitening Gel	Natural White Inc., Tonawanda, NY	8287N	11.13 ± 0.18
Natural White-Rapid White. Tooth Enamel Whitening System. Step3 Oral Rinse Neutralizer	Natural White Inc., Tonawanda, NY	8227N	9.40 ± 0.02
Natural White. 5-Minute Tooth Whitening System. Non-Peroxide Formula. Step1 Accelerator	Natural White Inc., Tonawanda, NY	9271N	7.56 ± 0.04
Natural White. 5-Minute Tooth Whitening System. Non-Peroxide Formula. Step2 Whitening Gel	Natural White Inc., Tonawanda, NY	9242N	5.09 ± 0.01
Natural White. 5-Minute Tooth Whitening System. Step 1 Bleaching Gel	Natural White Inc., Tonawanda, NY	9215N	6.99 ± 0.01
Natural White. 5-Minute Tooth Whitening System. Step 2 Oral Rinse	Natural White Inc., Tonawanda, NY	9224N	9.14 ± 0.03
		Mean	8.22 ± 2.0

bleaching step of most of these products, and some of the products were intended for overnight use (8 hours of continuous wear). The pH of the DSHB products was in general fairly neutral, ranging from 5.66 to 7.35 with a mean of 6.48. For comparison, the pH of Pepsi was 2.45 ± 0.02 and the pH of Coca Cola was 2.49 ± 0.02 . Many patients drink such carbonated drinks, and the low pH of these products may also damage the tooth surface.

The DSHB and the OTC whitening kits are usually in contact with the teeth for extended periods. In addition to their generally neutral pH, the DSHB products are used in a custom fitting tray made to minimize the contact of bleaching products with gingivae and other soft tissues. In contrast, the

Table 4 Mean pH of 9 tooth-whitening toothpastes

Product Name	Manufacturer	Lot #	Mean pH ± SD
Colgate Platinum Whitening Fluoride Toothpaste	Colgate Oral Pharmaceuticals, Inc., Canton, MA	911048	7.62 ± 0.03
Natural White-Rapid White Toothpaste	Natural White Inc., Tonawanda, NY		8.35 ± 0.02
Natural White-Rapid White Sensitive Whitening Toothpaste	Natural White Inc., Tonawanda, NY	9514N	7.44 ± 0.02
Natural White-Rapid White Tooth Enamel Whitening System. Pre-whitening Toothpaste	Natural White Inc., Tonawanda, NY	8250N	5.32 ± 0.15
Natural White. 5-Minute Tooth Whitening System. Non-Peroxide Formula. Whitening Toothpaste	Natural White Inc., Tonawanda, NY	9282N	7.64 ± 0.01
Opalescence Whitening Toothpaste	Ultradent Products, Inc., South Jordan, Utah	3LN1	6.57 ± 0.03
Pearl Drops Tooth Polish	Carter-Horner Inc., Mississauga, ON	9BK111	6.81 ± 0.03
Perfecta Whitening Toothpaste with Hydrogen Peroxide	Premier Dental Products Co., King of Prussia, PA	9276N	4.22 ± 0.02
Rembrandt Whitening Toothpaste	Den-Mat Corporation, Santa Maria, CA	173041	7.51 ± 0.26
		Mean	6.83 ± 1.27

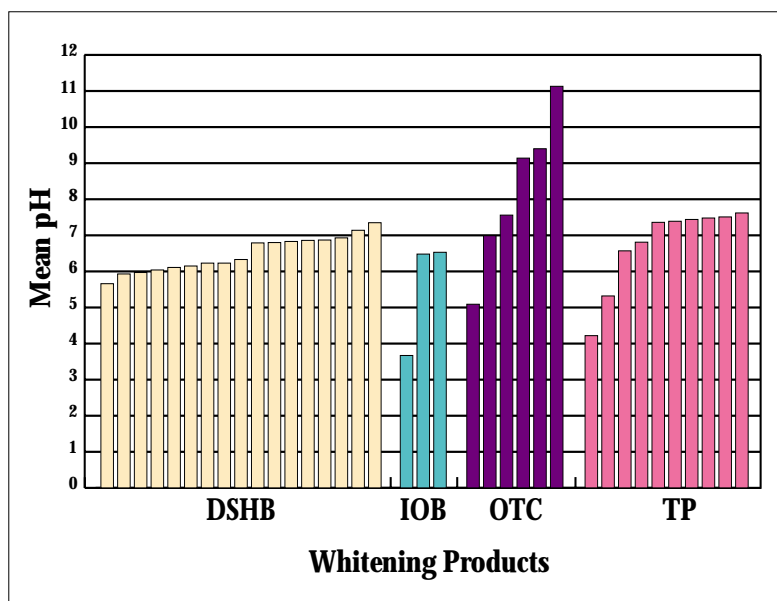


Figure 1: Mean pH of tooth-whitening products.

OTC products do not use custom fitting trays and sometimes contain rinses or gels that have to be brushed onto the teeth. These products had a wide range of pH (5.09 to 11.13) and are more likely to come in contact with oral tissues during the bleaching process. The manufacturers of the IOB products that have higher concentrations of peroxide recommend using a rubber dam or some other form of gingival protection to minimize the contact of bleaching products with the gingivae and other oral tissues.

It has been previously reported that enamel demineralization can occur at a pH lower than 5.2 to 5.8.²⁷ Other studies have shown that root resorption can occur when teeth are exposed to a low pH.^{18,26} One of the IOB products, Opalescence Xtra, had a pH of 3.67, the Perfecta Whitening toothpaste with hydrogen peroxide had a pH of 4.22, and the whitening gel of the OTC product Natural White, 5-minute Tooth Whitening System had a pH of 5.09. Consequently, these products may cause enamel demineralization.

It has also been suggested that it is the frequency of use of low-pH solutions, rather than the total time of exposure to them, that results in a non-proportional increase in enamel erosion.²⁸ Although products such as Colgate Platinum Overnight (pH 5.93 ± 0.08), Nupro Gold 10% (pH 5.97 ± 0.02) and Nupro Gold 15% (pH 6.04 ± 0.02) do not have highly acidic pHs, an 8-hour application every day for 10 to 14 days may be enough time to cause some damage. The non-tooth-whitening toothpaste, Colgate Total, had a relatively neutral pH of 7.39 ± 0.04. Whitening toothpastes, which are used every day, should definitely also have a neutral pH; however, the Perfecta Whitening toothpaste with hydrogen peroxide had a pH of 4.22. When this product is used as a toothpaste on a daily basis it may cause damage to teeth and restorations. Although IOB products (such as Opalescence Xtra, which contains 35% hydrogen peroxide and has a mean pH of 3.67 ± 0.06) are applied to the teeth for only 5 to 10 minutes and are activated by a curing light, it is not known whether that length of exposure at this pH could cause significant damage to teeth, restorations or oral tissues. Nonetheless, in view of the enamel demineralization that could occur at this low pH, it might be prudent to apply topical fluoride gel at the end of the IOB procedure when Opalescence Xtra is used.

The Whitening Gel of Natural White-Rapid White, an OTC product, had a mean pH of 11.13 ± 0.18. The OTC products are placed in a non-customized flexible tray that allows the bleaching

agent to contact both the teeth and the gingivae. The instructions recommend 10 minutes of continuous wear, which may have a deleterious effect on the oral tissues. Other products such as Natural White-Rapid White Toothpaste (pH 8.35 ± 0.02) are used twice a day for at least one minute as a regular brushing toothpaste. The effects of this repeated and prolonged exposure to such a basic pH requires further investigation.

The IOB kit that contained 35% hydrogen peroxide had the lowest pH of 3.67. The other 2 IOB products contained 35% carbamide peroxide (~12% hydrogen peroxide) and had more neutral pHs of 6.48 to 6.53. Also, the DSHB Perfecta Trio containing 16% carbamide peroxide had a lower pH (6.83) than the Perfecta Trio containing 11% carbamide peroxide (pH 7.35). These results support the finding that the greater the peroxide concentration, the more acidic the pH of the bleaching product.²⁶

Although this study measured the pH of 26 tooth-whitening products in vitro, there are many other tooth-whitening products that were not tested. The wide range in the pH of the whitening toothpastes and OTC products requires further investigation. Additionally, the pH of the bleaching agent has been reported to change inside the oral cavity during the bleaching process as the carbamide peroxide breaks down into hydrogen peroxide and urea. The hydrogen peroxide, in turn, breaks down into oxygen and water, and the urea degrades into ammonia and carbon dioxide. The release of ammonia and carbon dioxide elevates the pH of the bleaching agent in the oral cavity to a more basic environment within 15 minutes.^{13,36} It is not known if the pH of the products containing carbamide peroxide or hydrogen peroxide changes at the same rate, or if such changes in the pH may adversely affect the oral tissues during the whitening process. The intraoral temperature may also affect the pH. This study attempted to standardize the test conditions by measuring the pH at 22°C; however, the pH of whitening toothpastes may be affected by the temperature of the water used to brush the teeth, and the temperature of the IOB change as they are heated by the bleaching light.

Conclusion

It is evident from the literature that factors such as pH, acid concentration, temperature, exposure time and frequency of exposure can all contribute to enamel erosion and demineralization and may affect restorations as the patient attempts to whiten his or her teeth. Further research is needed to study the effects of these factors and to explore how the adverse effects of a low-pH tooth-whitening product could be minimized (e.g., by adding small amounts of calcium to the product).

It is important that the clinician understand the potential effects of prolonged exposure to low pH on teeth and restorations. Patients should be informed that prolonged or repeated use of some OTC, IOB and DSHB products may cause damage to the teeth and restorations, because of the low or high pH of the products. ♦

Acknowledgments: The authors would like to thank Dr. P. Andreou, biostatistician, for the statistical analyses. This study received financial support from the Faculty of Dentistry Alumni Oral Health Research Fund of Dalhousie University.

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The authors have no declared financial interest in any company manufacturing the types of products mentioned in this article.

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