The Effect of Bleaching Time on Dentin Fracture Toughness in Vitro

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ABSTRACT

Statement of Problem: A recent study reported a decrease in dentin fracture toughness after the application of peroxide bleaching products to dentin in vitro.

Purpose: The objective of the present study was to investigate this in vitro decrease in fracture toughness further by evaluating the effect of different peroxide application times on dentin fracture toughness.

Materials and Methods: Compact test fracture toughness specimens were prepared from coronal human. These were divided into five groups ($N = 12$) and subjected to either bleach (10% carbamide peroxide) and/or placebo gel for a total of 336 consecutive hours (0 and 336, 84 and 252, 168 and 168, 252 and 84, 336 and 0 hours of bleach and placebo application time, respectively). The gel materials were changed every 6 hours. Fracture toughness testing was done 24 hours after the end of bleaching using tensile loading at 10 mm/min. Results were analyzed by analysis of variance and linear regression ($p < 0.05$).

Results: Dentin fracture toughness after 252 and 336 hours was significantly reduced compared to the 0- and 84-hour bleach times. An association between fracture toughness and bleach time ($r^2 = 0.82$) with an inverse linear regression line ($K_{1C} = -0.0032$ [hour] + 3.386) was found.

Conclusions: A significant correlation was found between bleach time and dentin fracture toughness. Dentin fracture toughness was reduced over time during the 336-hour course of in vitro bleaching.

CLINICAL SIGNIFICANCE

The results suggest that it would be prudent to minimize the length of time for clinical bleaching procedures when dentin is directly exposed to bleach.

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INTRODUCTION

Bleaching agents, including carbamide peroxide, are used in varying concentrations and durations by patients and dentists to whiten discolored teeth. Hydrogen peroxide, a component of carbamide peroxide, acts as an oxidizing agent through the formation of free radicals, reactive oxygen molecules, and hydrogen peroxide anions. These reactive molecules attack and split apart chromophore stain molecules on teeth to create a whitening effect.[1]

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Surface morphology, hardness, and bonding studies have been used to evaluate the effects of bleach on dental hard tissues. The clinical relevance of an in vitro finding of reduced hardness or altered surface morphology after bleaching,[2–6] however, is uncertain because the effect appears limited to only the outermost microns of the dental hard tissue surface, which can be remineralized by saliva. The results of hardness studies reflect surface changes only, and do not characterize deeper changes that may impact tooth structural integrity. While it is intended that bleach is applied topically to the enamel surface, the effects of bleach are not necessarily restricted to enamel only. In cases of root exposure and occlusal attrition, bleach is applied directly to the dentin surface.

The structural integrity of teeth is best evaluated by strength and fracture toughness tests. Fracture toughness, K_{1C}, is the measure of a material's resistance to crack propagation[7] and relates to the amount of stress applied to the tip of a preexisting flaw prior to fracture. The mechanical property of dentin is significant as dentin provides the base for both enamel and cementum.

A previous study evaluated dentin fracture toughness after two time periods of simulated overnight bleaching.[8] Dentin fracture toughness was significantly lower after 8 weeks of bleaching than after 2 weeks. It was hypothesized that bleach application time had a significant effect on the structural integrity of dentin. The objective of this study was to determine if a correlation existed between dentin fracture toughness and bleach time.

MATERIALS AND METHODS

Specimen Fabrication Procedures

Extracted human molar teeth stored in 1% chloramine solution at 4°C for no more than 1 month were used for all experiments. Sixty teeth were included in the study. Molars with visible caries, cracks, and fractures were excluded.

A water-cooled low-speed diamond saw (Buehler Ltd, Lake Bluff, IL, USA) was used to first prepare a slice of coronal dentin with the orientation of the slice parallel to the occlusal surface of the molar. One slice was obtained from each tooth. All slices contained no enamel traces on the surface. The thickness (B) of each slice ranged from 1.6 to 2.0 mm.

The dentin slices were shaped into rectangular blocks with approximate dimensions of 4.5 mm (height) × 4.6 mm (C) × (B) using a carbide bur (Brasseler USA, Savannah, GA, USA) in a high-speed drill. Each specimen was then refined with Sof-Lex discs (3M ESPE, St. Paul, MN, USA) to final dimensions in accordance to those prescribed for compact tension specimens, ASTM E-399 (Figure 1).[9]

Two cylindrical holes were drilled into each specimen to provide the means of attachment to the Instron universal testing machine (Model 4301, Instron, Canton, MA, USA). A 1/4 round carbide bur (Brasseler USA) mounted on a low-speed drill was used in this procedure. The central notch was cut using a 0.4 mm-thick diamond disc (ThinFlex × 929.7, Abrasive Technology Premier Products, Plymouth Meeting, PA, USA) on a low-speed drill. The notch was then sharpened by applying hand pressure to a razor blade across the notch. The length of the central notch (a) was related to the net specimen width (W), determined by the specimen requirement:

$$0.45 \le a/W \le 0.55$$

All specimen dimensions were measured using a digital caliper, with an accuracy of ±0.02 mm (Mitutoyo Corporation, Kanagawa, Japan).

Bleaching Procedures

The fracture toughness specimens were randomly distributed into five groups ($N = 12$, Table 1). In the five groups, bleach (10% carbamide peroxide Opalescence, Lot# B3B6C, Ultradent Products Inc.,

TABLE 1. THE DENTIN FRACTURE TOUGHNESS RESULTS FOR EACH TEST GROUP ARE SHOWN.

Bleaching time (hours)	K_{1C} (MPa × $m^{1/2}$) mean	Standard deviation	*N*
0	3.3^{A}	1.1	12
84	3.2^{AB}	1.0	10
168	3.1^{ABC}	1.0	10
252	2.3^{C}	0.9	11
336	2.4^{C}	0.6	12

The superscript letters denote groups with no significant differences.

South Jordan, UT, USA) was applied to the specimens for 0 hours (Group A), 84 hours (Group B), 168 hours (Group C), 252 hours (Group D), and 336 hours (Group E). During the 336-hour window of time for material application, Group A (0 hours) was a control group so that only placebo gel, containing the same ingredients as the bleaching gel except for the active carbamide peroxide (Opalescence Placebo, Lot# B3B6C, Ultradent Products Inc.), was applied to the specimens. For Group B (84 hours), placebo gel was applied to the specimens from 0 to 252 hours, and bleach was applied at the 252nd hour for the next 84 hours. In the same manner, for Group C, bleach was applied at the 168th hour, and for Group D, bleach was applied at the 84th hour. Lastly, for Group E, the specimens were treated with bleach during the entire 2 weeks (336 hours), starting from 0 hours.

For each material application, the specimens were inserted into a custom-made bleaching tray to allow a 1-mm thick layer of bleach or placebo gel to engulf the specimen surfaces. The bleaching tray was then immersed in artificial saliva at 37°C for 6 hours to mimic one at-home overnight bleaching regimen. The stability of the incubator (Boekel Economy Analog Incubator, Medex Medical Supply/Monsey, NY, USA) at 37°C was ±1°C. After 6 hours, the bleach and placebo gels were rinsed with tap water to remove all external traces of gel. New bleach or placebo gel was applied for another 6 hours and these bleach or placebo treatments were repeated until the end of the bleach and placebo application time (336 hours). Thereafter, the specimens were stored in artificial saliva for 24 hours prior to fracture toughness testing.

Fracture Toughness Testing

The specimens were mounted onto an Instron universal testing machine for fracture toughness testing. Two round stainless steel wires with a diameter of 0.5 mm were utilized for attachment. The tensile loading was applied at a rate of 10 mm/min until specimen fracture. K_{1C} was calculated according to the following formula:

$$K_{1C} = \frac{P \times Y_2}{B \times W^{1/2}}$$

Where P = maximum load required to fracture the specimen (MPa), Y_2 = a tabulated function of a/W,[9] B = specimen thickness (m), and W = specimen net width (m).

The K_{1C} results were analyzed by analysis of variance (ANOVA), linear regression ($p < 0.05$), and Tukey's test.

RESULTS

Sixty specimens were subjected to fracture toughness. Five specimens were excluded from the ANOVA because specimen fracture occurred either at the mounting hole or away from the expected site of crack propagation. The mean K_{1C} and standard deviations are presented for each test group in Table 1 and are graphically represented in Figure 2. Dentin fracture toughness after 252 and 336 hours was significantly reduced compared to the 0-hour and 84-hour bleach times. An association between fracture toughness and bleach time ($r^2 = 0.82$) with an inverse linear

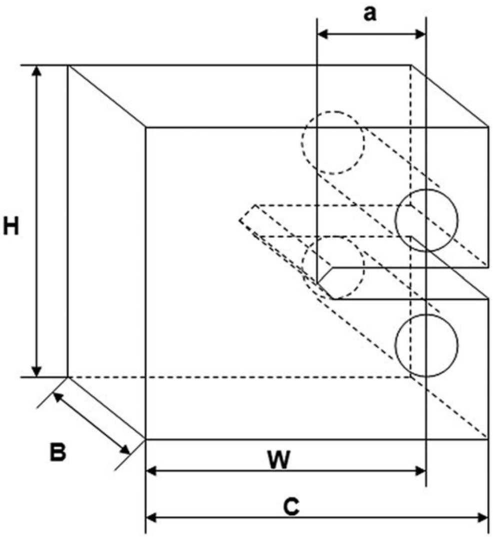

Figure 1. *Fracture toughness specimen. B = specimen thickness; H = specimen height; C = specimen width; W = net specimen width; a = net crack length length.*

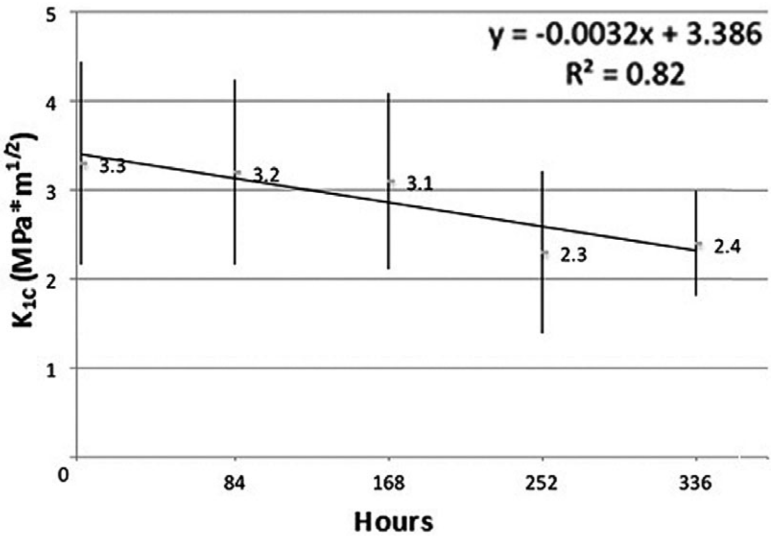

Figure 2. *Dentin fracture toughness results. The mean K_{1C} and standard deviations are shown. The least squares linear regression line and* R^2 *are also shown.*

regression line ($K_{1C} = -0.0032$ [hour] + 3.386) was found.

DISCUSSION

The 0-hour, 84-hour, 168-hour, 252-hour, and 336-hour bleaching time periods were chosen to represent 0-week, 2-week, 4-week, 6-week, and 8-week bleaching regimens, respectively, assuming overnight bleaching for 6 hours/day. The K_{1C} value for dentin in the placebo group of this study was similar to those reported in general for dentin[10] and in placebo groups of a previous bleach study.[8] The K_{1C} value for dentin in the 336-hour group (representative of an 8-week bleaching regimen) of this study, however, was higher than that reported for an 8-week bleach group of a previous bleach study.[8] The difference in bleach application protocols (with and without interim storage periods between successive bleach applications) might explain the difference between the 336-hour bleach result of this study and the 8-week bleach result of the previous study. The consecutive bleaching that was done in this study, with no interim periods between successive bleach applications, is not done clinically but was done in this study in order to study the effects of bleach application time without the possible confounding effects of an interim storage period in artificial saliva. The lower K_{1C} results of the previous study suggested that the interim artificial saliva storage did not prevent or restore the loss in dentin fracture toughness and may have enhanced the reduction in dentin fracture toughness by lengthening the overall study period to 8 weeks.

It is uncertain whether there is a potential for cumulative damage resulting from prolonged or multiple exposures to dental bleach. The results of this in vitro study suggest that there is an association between the length of bleaching time and dentin fracture toughness, and a relatively progressive reduction in dentin fracture toughness would be expected over the course of 336 hours of bleaching. The point at which the reduction in dentin fracture toughness becomes clinically significant is unknown and would depend on many factors. However, any reduction in dentin fracture toughness would be undesirable considering the stress and fatigue that a tooth must endure in a lifetime. The linear regression line result indicated an approximate 0.1% drop in dentin fracture toughness for each hour of bleaching up to 336 hours. The 252-hour and 336-hour K_{1C} results were significantly lower than the 0-hour and 84-hour K_{1C} results, suggesting a possible increased reduction in fracture toughness around the 168-hour time period. However, there were insufficient data to determine a nonlinear pattern of fracture toughness changes.

The results cannot be used to extrapolate beyond 336 hours. It is possible that the reduction in dentin fracture toughness is self-limiting or reverses in in vivo conditions. A comparison of in vitro and in situ effects of bleaching with carbamide peroxide on the hardness of enamel suggested that the in situ specimens were remineralized in the oral cavity.[11] Demineralization is a possible mechanism for reduced dentin fracture toughness.[12] Enamel, a highly mineralized tissue, had a significantly reduced mineral content on its surface after exposure to bleach.[12–15] The fracture toughness of enamel was also reduced after exposure to bleach.[16,17]

It has been demonstrated that, although the organic matrix of enamel comprised a small percentage (w/w) of enamel, it significantly influenced enamel's mechanical properties.[18] The organic matrix of dentin, like bone, comprises a significantly greater percentage (w/w) of dentin than enamel. The toughness and strength of bone has been shown to decrease with increasing collagen denaturation.[19] Chemical investigations suggested that hydrogen peroxide causes oxidation of the organic component of dentin.[20] Therefore, destruction of the organic components of dentin as a result of bleaching procedures could further explain reduced dentin fracture toughness over time.

In this study, bleach was applied directly to the dentin surface as opposed to the enamel surface. As a result, it is expected that the rate of dentin fracture toughness decrease over time is far greater in this study than in the clinical situation where bleach is applied primarily to the enamel surface. Bleach can diffuse through enamel as it has been shown that there is a reduction in dentin fracture toughness after a simulated clinical application of carbamide peroxide to the enamel surface,[8] and significant amounts of hydrogen peroxide can diffuse readily through a thickness of dentin.[21] These reports are in contrast to a study that suggested that the demineralization effects of bleaching using 10% carbamide peroxide bleach were confined to the outer 50-µm layer of enamel.[22] Bleach diffusion rates would be affected by a variety of factors including chemical potential gradients, surface attraction and bonding, and local architecture. It is anticipated that enamel cracks and dentinal tubules would facilitate the passage of bleach deeper into dentin.

CLINICAL IMPLICATIONS AND RELEVANCE TO ESTHETIC DENTISTRY

Changes in the structural integrity of dentin should be taken into consideration when bleaching is used as a treatment for whitening teeth. This study attempted to correlate bleach time and its effects on dentin fracture toughness. The results from this study showed that the length of bleach application time to dentin using 10% carbamide peroxide was inversely correlated with dentin fracture toughness in vitro. The rate of dentin fracture toughness decrease was related to the bleach diffusion rate as well as to the time required to demineralize dentin and to oxidize dentinal collagen.

The results suggest that it would be prudent to minimize the length of time for clinical bleaching procedures when dentin is directly exposed to bleach.

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