



## ORIGINAL ARTICLE

# Effect of home and in-office bleaching systems on the nanomechanical properties of tooth enamel



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## KEYWORDS

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Surface roughness

**Abstract Objectives:** The purpose of this in vitro laboratory study was to gauge the nanomechanical properties of the tooth enamel surface using home and in-office bleaching products.

**Methods:** Thirty-six extracted lower lateral incisor teeth (sound and without caries, cracks or restorations) were selected. A silicone mould was used to affix the samples in resin after cutting away the roots. Next, the samples were indiscriminately divided into three treatment groups, i.e., 12 teeth in each study group (control, Opalescence Home, and Opalescence Boost), and treated according to their respective group procedures. Surface topography, nano-indentation, and visual analyses were performed. Data were examined statistically using one-way analysis of variance ( $p < 0.05$ )

**Results:** Both experimental bleaching products enhanced the surface roughness when compared to the samples in the control group. However, the control and Opalescence Boost groups showed insignificant differences. The lowest mean nanohardness (GPa) was observed in the Opalescence Boost group ( $1.56 \text{ GPa} \pm 0.68 \text{ GPa}$ ). In contrast, the highest mean nanohardness (GPa) was perceived in the control group ( $3.53 \text{ GPa} \pm 1.06 \text{ GPa}$ ). The modulus of elasticity was highly affected using Opalescence Boost ( $182.63 \text{ GPa} \pm 109.13 \text{ GPa}$ ) when compared to Control ( $322.69 \text{ GPa} \pm 168.24 \text{ GPa}$ ). On visual examination, pronounced roughness was observed in both the Opalescence Home and Opalescence Boost groups.

**Conclusion:** Both teeth whitening products damaged the enamel surface either by roughening the tooth surface or by affecting the nanomechanical properties. Therefore, teeth whitening products may be used, but with great caution.

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## 1. Introduction

Tooth discoloration is a crucial problem affecting both the primary and secondary teeth. In the UK alone, 28% of the adults are displeased with the appearance of their teeth (Qualtrough and Burke, 1994). However, this figure increases to 34% in

the USA (Odioso et al., 2000). The ideal esthetic smile is a rudimentary aim in dentistry. Recently, cosmetic dentistry has gained importance and bleaching is considered one of the most popular cosmetic dental procedures (Pimenta-Dutra et al., 2017).

Today, plenty of whitening products, generally categorized into home bleaching (popular and easy to use with mild to moderate concentration of peroxide for multiple applications) are available in the market. However, in-office bleaching is performed in a single visit with a much stronger concentration of peroxide (Alqahtani, 2014). Hydrogen peroxide is a widely used bleaching agent. Other commonly used bleaching agents include chlorides, peroxides, and chlorine. However, the inactive constituents may comprise of: gelling agents to increase the viscosity, carrier such as glycerine to maintain moisture, surfactant or a surface-wetting agent, preservative such as methyl or sodium benzoate to prevent bacterial growth, and flavoring agents to improve taste (Alqahtani, 2014).

Regardless of the proposed advantages of vital tooth whitening, there are also some undesirable effects such as tooth sensitivity (Basting et al., 2005), changes in surface morphology (Dildeep and Vishwanath, 2003), decrease in microhardness (Attin et al., 2005), and changes in the chemical composition (Lee et al., 2006). The significance of interpreting the effect of bleaching products on the enamel surface, particularly hardness, can help in administering the right dose of the bleaching agent on the vital teeth, considering the safety of the tooth structure and concurrently obtaining the best bleaching effects with maximum preservation of dental tissues (Mondelli et al., 2015).

Although tooth whitening is a widely studied process with abundant available literature, some of this literature shows conflicting results relating to surface roughness and microhardness tests, and some studies even report wear of enamel as well as dentine on using bleaching products (Bizhang et al., 2009; Joiner, 2006). Meanwhile, other studies report no detrimental effects of bleaching products on the microhardness of the teeth (De Abreu et al., 2011). However, the surface of the teeth might get roughened due to bleaching of enamel (Moraes et al., 2006). To the best of the authors' information, no data on the examination of the effect of bleaching products at the nano-level is available. Hence, this study was envisaged to examine the nano-mechanical properties of tooth enamel using two commercially available bleaching products (one home and one in-office bleaching agent). It was hypothesized that more the concentration of the bleaching gel, greater the effect on the nano-mechanical properties of the enamel.

## 2. Materials and methods

A total of forty-one mandibular lateral incisor teeth were procured from the King Khalid University Hospital, Riyadh, Saudi Arabia, and selected for the study. Inclusion criteria for the teeth were: sound condition (i.e., without any caries, cracks, and restoration) and the extracted teeth must belong to patients aged between 18 and 46 years. Initially, all the extracted teeth were cleaned with water using a soft toothbrush. Next, the teeth were stored in distilled water for seven days before any further procedures. On the eighth day, a diamond saw (Isomet 5000; Buehler Ltd, USA) was used with a

slow-speed motor to notch the roots approximately 1–2 mm in the apical third to the cemento-enamel junction.

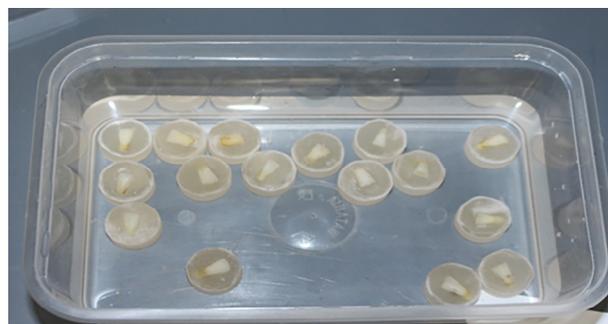
A stereomicroscope was used to find out any stains or cracks in all the teeth using a magnification of 25x. After performing the power sample calculation test, a total of 36 teeth were finalized for the experimental procedures and assigned to three study groups ( $n = 12$ ) conforming to the bleaching agents used: control (no treatment), Opalescence home (containing 15% carbamide peroxide), and Opalescence Boost (containing 40% hydrogen peroxide).

A silicone mould of 20 mm diameter and 15 mm height was used to affix the teeth in self-curing acrylic resin (Eco Cyl Cold, Protechno, Spain). The long axis of each tooth was placed horizontally on the acrylic resin at the time of setting, as can be seen in Fig. 1. All the 36 teeth were embedded in circular blocks using silicon as the adhesive material between the teeth and the surface of the circular blocks (Fig. 1). Next, the embedded samples were left at room temperature for 24 h to strengthen the bonding. The samples were randomly divided into three treatment groups and treated in line with their respective group procedures.

For the control group ( $n = 12$ ), all the sample teeth were saved in distilled water for seven consecutive days at a controlled temperature of  $35 \pm 1^\circ\text{C}$ . However, the sample teeth from the Opalescence Home group (Ultradent, UT, USA) were exposed to 2 h gel treatment daily for four consecutive days. After the treatment, the sample teeth were again saved in distilled water. On the 4th day of treatment, the sample teeth were ready for testing. On the contrary, for the Opalescence Boost group (Ultradent, UT, USA), the gel was administered on the sample teeth for 20 min. Next, the whitening gel was cleansed with water, and an interval period of 20 min was given prior to the repeat administration for 20 min. In the end, all the sample teeth were washed with water again and stored in distilled water for 24 h. After 24 h, the sample teeth were ready for testing.

### 2.1. Surface roughness measurement

Surface roughness measurements were made using a 3D optical surface profiler (UMT 1, Bruker, USA). The samples were placed on a vibration isolation table under a camera having a 5x magnification. The measurements and precision of surface roughness parameters were controlled by a proprietary software named Vision64 (v 5.30). Surface roughness values of



**Fig. 1** Mandibular lateral incisor teeth embedded in resin blocks before any treatment protocol.

all the three study groups were determined. The amplitude property noted for surface roughness value was Sa.

### 2.2. Nanohardness and elastic modulus computation

Surface nanohardness of the sample teeth were estimated using a nano-mechanical tester (Bruker, USA). All the readings were performed at room temperature ( $27\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ ) with negligible noise conditions (RMS [RMS = root mean square]  $< 5\text{ mV}$ ). The loading and unloading rates were set at  $2.0\text{ mN/s}$ . The maximum load time was  $10\text{ s}$  and it was set to  $50.0\text{ mN}$ . Each sample received three indentations of maximum load at different regions on the surface.

### 2.3. Stereomicroscope images

A stereomicroscope (Nikon SM2-10, Tokyo, Japan) was used to visualize the surface texture of each sample tooth after treatment, at a magnification of  $25\times$ .

### 2.4. Statistical analysis

Software SPSS ver.21 (SPSS 21.0 for Windows, USA) was used to accomplish the statistical investigation. Level of significance among the groups was set at a p-value of less than  $0.05$ , and it was deduced by the one-way analysis of variance statistical method (ANOVA). Furthermore, the Tukey's test was employed to statistically differentiate within the groups ( $p < 0.05$ ).

## 3. Results

Fig. 2 presents the mean surface roughness values of the study groups. The lowest mean surface roughness was perceived in the control group ( $0.12\text{ }\mu\text{m} \pm 0.06\text{ }\mu\text{m}$ ). Whereas, the highest mean surface roughness was perceived in the Opalescence home group ( $0.18\text{ }\mu\text{m} \pm 0.04\text{ }\mu\text{m}$ ). According to the analysis of variance, a significant difference was observed within the testing groups ( $p = 0.03$ ). Furthermore, Tukey's test revealed

a significant difference between the Control and Opalescence Home groups. However, no significant difference was perceived between the Control and Opalescence Boost groups or between Opalescence Home and Opalescence Boost groups.

Fig. 3 presents the mean nanohardness values of the study groups. The lowest nanohardness was perceived in the Opalescence Boost group ( $1.56\text{ GPa} \pm 0.68\text{ GPa}$ ). In contrast, the highest nanohardness was perceived in the control group ( $3.53\text{ GPa} \pm 1.06\text{ GPa}$ ). According to ANOVA, statistical differences were observed within the testing groups ( $p < 0.001$ ). Furthermore, Tukey's test revealed a significant difference between the Control and Opalescence Boost groups and between the Opalescence Home and Opalescence Boost groups.

Fig. 4 presents the mean elastic modulus values of the three study groups. The highest modulus of elasticity value was perceived in the control group ( $322.68\text{ GPa} \pm 168.24\text{ GPa}$ ), whereas, the lowest was perceived in the Opalescence Boost group ( $182.63\text{ GPa} \pm 109.12\text{ GPa}$ ). Statistically insignificant differences were detected between the study groups.

Fig. 5 demonstrates the stereomicroscopic images of the tooth enamel exposed to different bleaching materials. Visual analysis suggests pronounced surface roughness in the Opalescence Home group, as shown in Fig. 5b (scale bar =  $1\text{ mm}$ ). Sample of the control group showed a shiny and smooth texture (Fig. 5a).

## 4. Discussion

The data suggest partial acceptance of the working hypotheses. Opalescence Boost affected the surface nanohardness and modulus of elasticity of the teeth surfaces. However, a statistically insignificant difference was perceived between the groups with regard to the surface roughness parameter.

Although many products are available in the market, Opalescence tooth whitening products were selected for both home bleaching and in-office bleaching. For the validity and reliability of the study findings, it was necessary to employ human teeth that were not only freshly extracted but also sound and crack- and caries-free. Furthermore, lower lateral

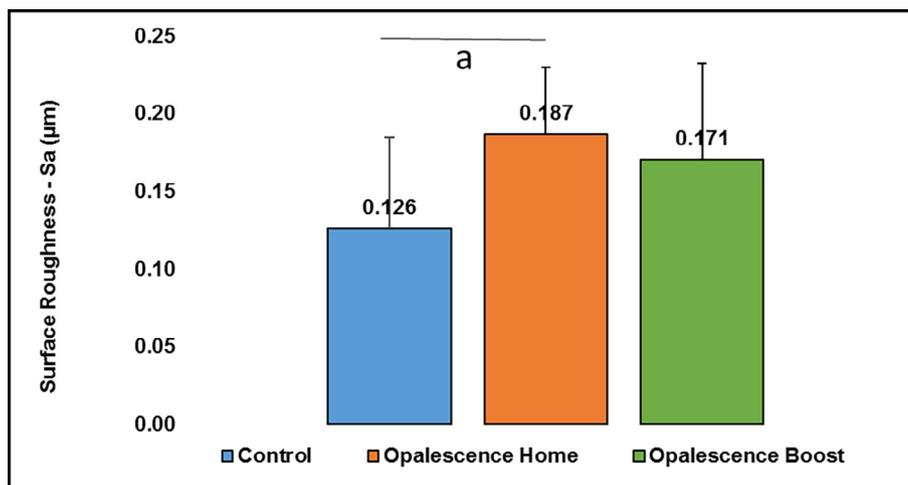
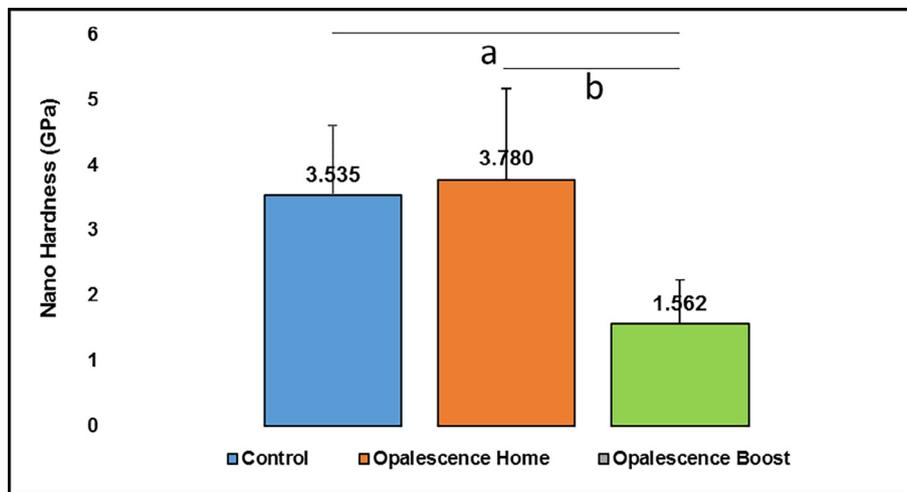
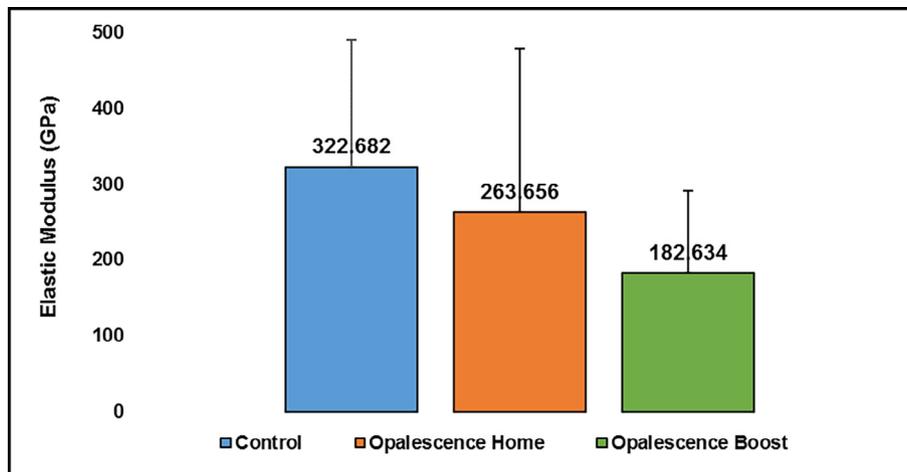


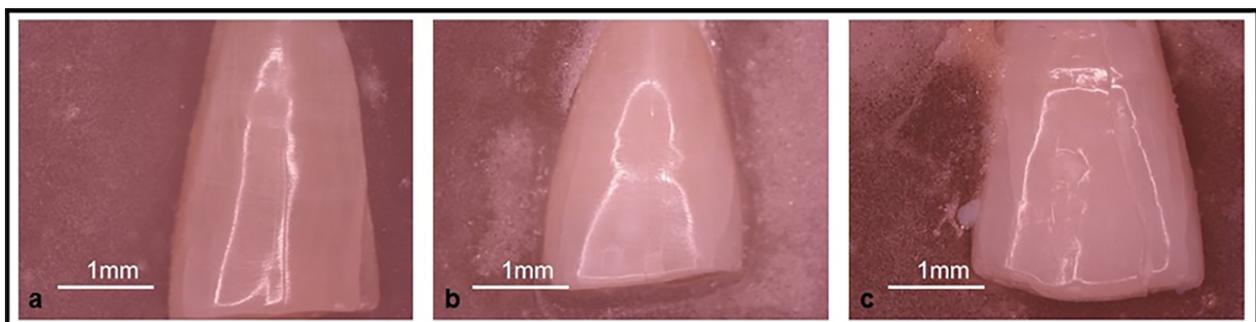
Fig. 2 Graphical representation of the mean surface roughness of the three study groups. Lower case letter represent the statistical differences within the groups.



**Fig. 3** Graphical representation of mean nano hardness of the study groups. Lower case letters represent the statistical differences within the groups.



**Fig. 4** Graphical representation of the mean elastic modulus of the three study groups. N.B. No statistical difference was observed within the groups.



**Fig. 5** Stereomicroscope images of sample teeth (a) Control group (b) Opalescence Home group after treatment (c) Opalescence Boost group after treatment.

incisors were selectively chosen because their shape is flat overall when compared to the other teeth, making it more feasible to measure the surface roughness and nano-indentations.

Both experimental groups produced higher surface roughness on the enamel when compared to the controls, i.e., the untreated group. However, the Opalescence Boost group did

not show statistically higher surface roughness values. Although Opalescence Boost contains 40% hydrogen peroxide, added buffers such as potassium nitrate and fluoride might have helped to maintain a neutral pH. Hence, no immediate effect on surface roughness was seen. These findings are in accordance with those of Cadenaro et al., who found that in-office bleaching had a non-effective influence on tooth surface roughness (Cadenaro et al., 2006). On the contrary, the Opalescence Home group showed significantly higher surface roughness than the control and Opalescence Boost groups. Regardless of the low concentration of carbamide peroxide (15%) in Opalescence Home bleaching, the home bleaching product was used for continued periods and for a considerable duration in this study. The contact time between Opalescence Home and the teeth was much longer than that in the case of Opalescence Boost bleaching. This might increase the chance of possible damage to the hard tissue, i.e., enamel (Cavalli et al., 2011). Secondly, without the buffering effect of saliva, these destructive effects on enamel might become more pronounced. This might be the reason for the surface roughness in the Opalescence Home group when compared to the other groups.

Surface hardness is an important mechanical property (Khan et al., 2015). However, nanohardness is a valuable method for quantifying the unit area of the indented surface at the nanoscale (Khan et al., 2018). A significant reduction in the nanohardness of human enamel after the application of Opalescence Boost was observed. However, no reduction in nanohardness after the application of Opalescence Home was observed. These results are in harmony with the previous findings (Basting et al., 2003; Azer et al., 2009). One of the main reasons for these debatable results of the nanohardness studies could be the large regional variations in the structure of human enamel, related to the differences in local chemistry (altered levels of mineralization, organic matter and water) and microstructure (fractions of inorganic crystals and organic matrix) (Braly et al., 2007; Spalding et al., 2003). Enamel nanohardness may consequently vary from area to area.

As expected, the highest modulus of elasticity values were observed in the control group and the lowest was observed in the Opalescence Boost group. The depletion of modulus of elasticity values after bleaching is due to the destruction of the characteristic features of the protein structure found between the hydroxyapatite crystals, as evidenced by Zimmerman et al. using fluorescence specifically at the surface enamel (Zimmerman et al., 2010). With Raman/fluorescence spectroscopy, the investigators discovered substantial depletion of fluorescence concentration in the hydrogen peroxide-treated group, proposing that the organic matrix of the enamel may be significantly influenced by tooth bleaching. The findings of this study are in accordance with the previous studies that suggested that the reduction of modulus of elasticity is dependent on the concentration or pH of the whitening products (Azer et al., 2009; Alqahtani, 2014).

In this study, distilled water was used to store the samples. Most of the previous studies used artificial saliva as the storage medium to simulate oral conditions. The teeth selected for analyzing the effect of the bleaching agents were taken from patients within the age range of 18–46 years. This might have influenced the outcome of the results. It might be possible that younger patients' teeth are more resistant to bleaching effects due to stronger hydroxyapatite when compared to the teeth

of older patients. For future works, it will be exciting to assess the effect of bleaching products under different immersion media. The biocompatibility evaluation should be performed in future to systemically analyze the effects of bleaching products on the local tissues; studies related to fluoride-based bleaching agents will be interesting to evaluate.

## 5. Conclusions

Taking everything into account, it will be appropriate to say that higher surface roughness values were observed in the Opalescence Home group when compared to the control and Opalescence Boost groups. Moreover, nanohardness values of the teeth were significantly reduced in the Opalescence Boost group. Likewise, the modulus of elasticity of the teeth was also observed to be lowest in the Opalescence Boost group.

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## Ethical statement

In this laboratory study no animal or human subject was involved. Thus, this study need not any ethical approval.

## Declaration of Competing Interest

All the authors of this laboratory study declare no conflict of interest

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