The Influence of the Nd:YAG Laser Bleaching on Physical and Mechanical Properties of the Dental Enamel

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Received 8 August 2007; revised 6 October 2008; accepted 21 October 2008
Published online 15 December 2008 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/jbm.b.31297

Abstract: ***Background and Objectives:*** **The Nd:YAG laser can be used in Dentistry to remove soft tissue, disinfect canals in endodontic procedures and prevent caries. However, there is no protocol for Nd:YAG laser application in dental bleaching. The aims of this in vitro study were: (a) to observe the tooth shade alteration when hydrogen peroxide whitening procedures are associated with dyes with different wavelengths and irradiated with Nd:YAG laser or halogen light; (b) to measure the Vickers (VHN) enamel microhardness before and after the whitening procedure; (c) to evaluate the tensile bond strength of two types of adhesive systems applied on bleached enamel; (d) to observe the failure pattern after bond strength testing; (e) to evaluate the pulpal temperature during the bleaching procedures with halogen light or laser; (f) to measure the kinetic reaction of hydrogen peroxide.** ***Materials and Methods:*** **Extracted sound human molar crowns were sectioned in the mesiodistal direction to obtain 150 fragments that were divided into five groups for each adhesive system: WL (H_2O_2 + thickener and Nd:YAG), WH (H_2O_2 + thickener and halogen light), QL (H_2O_2 + carbopol + Q-switch and Nd:YAG), QH (H_2O_2 + carbopol + Q-switch and halogen light), and C (Control, without whitening agent). Shade assessment was made with a shade guide and the microhardness tests were performed before and after the bleaching procedures. Immediately afterwards, the groups were restored with the adhesive systems Adper Single Bond 2 or Solobond M plus composite resin, and the tensile bond strength test was performed. The temperature was measured by thermocouples placed on the enamel surface and intrapulpal chamber. The kinetics of hydrogen peroxide was observed by ultraviolet analysis.** ***Results*****: The shade changed seven levels for Nd:YAG laser groups and eight levels for halogen light. According to the student's *t*-test, there was no statistical difference between the VHN before and after the whitening protocols ($p > 0.05$). The tensile bond strength showed no statistical significance between the test groups and the controls, considering both adhesive systems tested by ANOVA and Tukey tests ($p > 0.05$). The predominant failure pattern after bond strength testing was mixed. The temperature was safe for laser and halogen light. The kinetic reaction showed that after 5 min all the hydrogen peroxide had been consumed.** ***Conclusions:*** **Nd:YAG laser associated with hydrogen peroxide bleached the enamel, the shade being similar to that obtained with the traditional method performed with halogen light. Moreover, the Vickers' microhardness and bond strength values were not altered in comparison with those for nonbleached enamel.**
 J Biomed Mater Res Part B: Appl Biomater 90B: 388–395, 2009

Keywords: **enamel; tooth bleaching; microhardness; bond strength test; laser**

INTRODUCTION

In the late 1980's, Haywood and Heymann[1] presented a new tooth bleaching technique with a low carbamide

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peroxide concentration, performed at home by the patients. Since then, tooth whitening treatment has gained popularity, and many techniques with different peroxide concentrations and activation of these agents with light sources have been studied, particularly with regard to the systemic effects on human beings, and the deleterious effects on dental structures. There are two techniques for bleaching vital teeth: in-office under the supervision of a dentist, or at-home, usually with the use of night guards and carbamide peroxide or hydrogen peroxide. The advantages of the in-office bleaching procedure are that the professional controls the contact of whitening agents with soft tissues that sometimes present sensitivity to peroxides, as well as the time of bleaching agent in contact with the tooth; specific parts, such as the cervical areas of teeth can be bleached; the patient spends less time on the treatment and immediate results can be observed after two or three visits. However, at-home bleaching gained popularity because of its simplicity, being a lower cost procedure in comparison with in-office treatment, being easy to use by patients, having presenting excellent scientific support. Nevertheless, tooth and soft tissue sensitivity, incorrect use by patients and overexposure to the over-the-counter products without professional control are common problems encountered with this technique.

Both techniques are capable of producing alterations in the micro morphology of the bleached enamel, with increase in porosity and tissue permeability.[2] These alterations could influence adhesive system bond strength due the difficulty of spreading adhesive in these areas. Moreover, these flaws can be oxygen reserves that decrease the polymerization rates of the adhesive, thereby decreasing its bond strength value and stability.[3] Researches concerning new tooth whitening techniques that suppress or decrease the adverse effects, and treatment chair time, as well as studies about different light sources for activating the peroxides have been conducted.

Today there are three lasers approved by FDA for tooth whitening: argon, carbon dioxide, and diode. Dostalova et al.[4] showed that two diode laser systems for activating peroxide-based bleaching agents reduced the clinical chair time. Luk et al.[5] combined five brands of agents with halogen light, infrared, argon laser, and carbon dioxide laser and found significant correlation between the type of bleaching agent and the light source, as regards shade change and temperature generated on tooth surfaces.

However, there is a certain amount of sensationalism as regards tooth bleaching with lasers, which sometimes presents poor esthetic results. This occurs because of the incorrect use of laser parameters that raise the tooth temperature, causing deleterious effects, particularly as a result of the application of a bleaching gel without the specific wavelength of the laser used. Moreover, incorrect advertising of whitening therapies applied in one session has created insecurity as regards this treatment. Studies are needed about new lasers and bleaching products with specific properties to work with them. One of these lasers, the Nd:YAG, has a strong potential for whitening teeth, because it produces the heat necessary for activating the hydrogen peroxide and the analgesia produced in the pulp by biostimulation. Moreover, this laser presents a multidisciplinary characteristic and has many applications, for example: soft tissue surgery, canal disinfection in endodontic procedures, pit and fissure sealing, it improves the fluoride uptake in enamel, promotes dentin melting creating a natural seal on exposed dentin, which causes pain in the cervical areas of teeth.[6] Studies about Nd:YAG laser have reported chemical changes in the dental structure, promoting the melting of dental hard tissues (dentin and enamel), increasing the distribution of calcium, phosphorus, magnesium, and oxygen in the enamel, making it acid resistant.[7] However, this type of laser presents a wavelength of 1064 nm which, when irradiated on an enamel surface, produces a limited result because of the wavelength of hydroxyapatite (λ = 2930 nm).[6] The application of dyes, which have a wavelength similar to that of Nd:YAG laser, on dental hard tissues, allows the surfaces to absorb the laser light efficiently, with a lower percentage of reflection or transmission by tissues.[6] Therefore, a way of making this technology feasible for dental whitening procedures is to associate dyes of similar wavelength, for example Q-switch (Kodak), with Nd:YAG laser and peroxide. The Q-switch (λ = 1051 nm) is a nontoxic dye described by the following chemical formula:

8-(5-(2,4-Bis(4-pentyloxyphenyl)-6,7-dihydro-5H-benzopyran-8-yl)-2,4-pentadienylidene)-2,4-bis(4-pentyloxyphenyl)-5,6,7,8-tetrahydro-1-benzopyrilium.

Therefore, the aim of the present study was to assess: the influence of halogen light or Nd:YAG laser associated with hydrogen peroxide on shade alteration, surface temperature, Vickers microhardness, bond strength of two adhesive systems to dental enamel surfaces, to observe the failure mode after bond strength testing and to detect the dye absorbance levels with ultraviolet analysis.

The initial null hypotheses of this study were:

- After bleaching the enamel with Nd:YAG laser there would be no alteration in enamel shade in comparison with the enamel not submitted to the whitening procedure.
- The Vickers microhardness and bond strength values would not be altered when compared with those of nonbleached enamel.
- The surface temperature during the procedure with laser would not exceed 42°C (5°C above normal body temperature of 37°C).

MATERIALS AND METHODS

The local research ethics committee approved protocol of this study (Protocol # 0374.0.002.000-06). Seventy-five

TABLE I. Shade Ranking From 1 to 16 (Lower to Higher)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
B1	A1	B2	D2	A2	C1	C2	D4	A3	D3	B3	A3,5	B4	C3	A4	C4

sound extracted human third molars were stored in 0.5% chloramine solution for 48 h for disinfection, and then kept in distilled water at 4°C until required for the experiment. The tooth crowns were sectioned in the mesial-distal direction in a cutting machine (Labcut 1010, Extec, London, England), to obtain two specimens, one buccal and one lingual, for each tooth. Next, they were embedded in autopolymerizing acrylic resin (JET, Classico, Rio de Janeiro, RJ, Brazil) so that the buccal/lingual surface faced upwards and the dentin faced the acrylic resin. After that the enamel surface was flattened in a polishing machine (DPU 10, Struers, Panambra, São Paulo, SP, Brazil) and polished with SIC abrasive papers # 600, 1000, and 1200 under water cooling. They were identified in sequential Arabic numerals from 1 to 150 and kept in artificial saliva at 37°C.

The factors under study were: shade assessment before and after bleaching procedures, enamel Vickers microhardness, tensile bond strength test of two adhesive systems applied after the whitening procedures and the temperature of enamel surface during the bleaching procedure with halogen or laser light.

Shade Assessment

Two previously calibrated observers used the Vita Color scale LI-Vita (VITA, Bad Säckingen, Germany) to compare the shade. The specimens ($n = 150$) were placed in a tray partially filled with distilled water, to prevent dehydration. At the moment of shade evaluation, the observer applied a black plastic circle with a central hole with 1.0 cm radius to evidence only the central portion of the enamel on each specimen. The observations were made in a place with natural light, between 11 am and 12 am, before the whitening treatments (initial shade) and 1 week later, after the whitening procedures (final shade), under the same conditions mentioned above.

The shade values were transformed into scores, that is, numbers as shown in Table I, in accordance with the information described by Kihn et al.,[8] Collins et al.,[9] Browning,[10] and Zantner et al.[11]

Vickers Microhardness Test

After the shade assessment, the specimens ($n = 150$) were submitted to the Vickers microhardness test (HMV-2, Shimadzu, Tokyo, Japan), a load of 200 g being applied for 5 s. Three measurements were obtained under 40× magnification for each specimen, and the mean of these values was considered as the initial Vickers number (initial VHN). After the whitening procedures, the specimens were kept in artificial saliva for 1 week and the same VHN measuring protocol was again applied (final VHN).

Whitening Protocols

The specimens, divided in groups as shown in Table II, received the whitening procedures described in Table III.

Tensile Bond Strength Test

After the whitening procedures, final shade selection and microhardness testing, the specimens ($n = 15$ per group) were removed from the artificial saliva after 2 weeks and subdivided into 10 groups as shown in Table I, to perform the tensile bond strength test, as follows:

Groups 1–5: The enamel received the adhesive Adper Single Bond 2 protocol with aid of a circular matrix with a central hole, and a truncated cone shape (base with 1.8 mm diameter, top of 4.0 mm and 4.0 mm height). The composite resin cone was built with Polofil Supra (Cuxhaven, Voco, Germany) shade A3 with two increments of 2.0 mm and light-polymerized with a halogen unit (XL 3000, 3M-ESPE, St. Paul, MN). The adhesive system and composite resin applications followed the manufacturers' instructions.

TABLE II. Groups Divided According to the Whitening Agent Type, Light Source, and Adhesive System

Group	*n*	Whitening Agent	Light Source	Adhesive Systems
1 (WLB)	15	H_2O_2 + thickener	Nd:YAG laser	Adper Single Bond 2
2 (WHB)	15	H_2O_2 + thickener	Halogen light	Adper Single Bond 2
3 (QLB)	15	H_2O_2 + carbopol + Q-switch	Nd:YAG laser	Adper Single Bond 2
4 (QHB)	15	H_2O_2 + carbopol + Q-switch	Halogen light	Adper Single Bond 2
5 (CB)	15	No (control)	No light (control)	Adper Single Bond 2
6 (WLS)	15	H_2O_2 + thickener	Nd:YAG laser	Solobond M
7 (WHS)	15	H_2O_2 + thickener	Halogen light	Solobond M
8 (QLS)	15	H_2O_2 + carbopol + Q-switch	Nd:YAG laser	Solobond M
9 (QHS)	15	H_2O_2+carbopol+Q-switch	Halogen light	Solobond M
10 (CS)	15	No (control)	No light (control)	Solobond M

TABLE III. Whitening Protocols

Groups	Whitening Agent	Photoactivation	Protocol
G1, G6 (WL)	Whiteness HP Maxx[a] (3 drops H_2O_2 + 1 drop thickener)	Nd:YAG laser[b] (100 mJ, 25Hz, 2.5W, 79.62 J/cm^2)	Gel light activated for 2min, gel removed with air-water spray, kept in artificial saliva for 1 week, second application of protocol previously described
G2, G7 (WH)	Whiteness HP Maxx (3 drops H_2O_2 + 1 drop thickener)	Halogen light[c] with 400 mW/cm^2	Gel application on enamel for 1 min, light activated for 40s, 10 min on enamel without photoactivation, spray air-water, second application of the protocol previously described, air-water spray, kept in artificial saliva for 1 week, re-application of the protocol
G3, G8 (QL)	Gel (3 drops H_2O_2+ 2 drop carbopol + 0.1 g Q-switch[d])	Nd:YAG laser (100 mJ, 25Hz, 2.5W, 79.62 J/cm^2)	Gel light activated for 2 min, gel removed with air-water spray, kept in artificial saliva for 1 week, second application of protocol previously described
G4, G9 (QH)	Gel- 3 drops H_2O_2+ 2 drop carbopol+ 0.1g Q-switch	Halogen light with 400 mW/cm^2	Gel application on enamel for 1 min., light activated for 40s, 10 min on enamel without photoactivation, spray air-water, second application of the protocol previously described, air-water spray, kept in artificial saliva for 1 week, re-application of the protocol
G5, G10 (C)	–	–	–

[a] Whiteness HP Maxx (FGM, Joinville, Brazil).
[b] Nd:YAG laser (Pulsemaster 1000, American Dental Technologies).
[c] Halogen light (XL3000, 3M-ESPE, St. Paul, MN).
[d] Q-switch.

Groups 6–10: Solobond M adhesive system (Voco, Cuxhaven, Germany) was applied on enamel and a composite resin cone was built as described for Groups 1–5. The adhesive system and composite resin applications followed the manufacturers' instructions.

After 48 h storage in artificial saliva at 37°C, the specimens were tested in a universal testing machine EMIC DL-2000 (São José dos Pinhais, Paraná, Brazil) with a cross-head speed of 0.5 mm/min.

Failure Analysis

After the tensile bond strength test, the failure mode was analyzed by scanning electronic microscopy (SEM). The specimens (n = 15 per group) were cleaned with acetone in an ultrasonic bath (Ultrasonic, Cleaner USC 700, São Paulo, SP, Brazil) for 10 min and left in absorbent paper at room temperature for 48 h. Next, the specimens were kept under low vacuum for 2 weeks. After drying, the specimens were sputter coated with 10 mA gold (Balzers Sputter Coater, Bal Tec AG, Furstentum, Liechtenstein) for 1 min and observed by SEM (Philips XL30, Eindhoven, Netherlands). The failures were classified as follows:

1. Adhesive: enamel/adhesive interface breaking without the adhesive on enamel surface,
2. Cohesive in enamel,
3. Cohesive in composite resin, and
4. Mixed: presence of adhesive and cohesive in enamel/composite resin.

Ultraviolet Dye Analysis

A drop of thickener (Whiteness HP Maxx, FGM, Joinville, SC, Brazil) was diluted in water and placed in the Visible Ultraviolet Spectrophotometer (HP model 8453, Hewlett Packard, Wilmington, DE). The same protocol was used for the Q-switch dye, but it was dissolved in acetone. Three evaluations of each dye were performed.

After absorbance data acquisition, the reaction kinetics between the dyes and hydrogen peroxide was performed. One drop of the thickener and three drops of the hydrogen peroxide were used and a thin coating of the mixture was placed on the visible ultraviolet spectrophotometer. The software command for the kinetic testing was sent, using the wavelength parameters of 332 nm and 508 nm for a15 s/cycle with total time of 600 s. The same was performed with the H_2O_2 + carbopol + Q-switch and the wavelength parameters were 992 nm and 1062 nm for a 15 s/cycle with total time of 600 s.

Surface and Pulp Chamber Temperature Measurement

Six human molar crowns were sectioned in the mesiodistal direction with a cutting machine to obtain two parts. The room temperature and relative humidity were maintained at 23°C and 50%, respectively, controlled by a thermo hygrometer (Testo, São Paulo, SP, Brazil).

A thermocouple (Salvterm 1200, Salcas, São Paulo, SP, Brazil) was placed on the enamel surface and the temperature reading was recorded in degrees Celsius (°C) after

TABLE IV. Initial and Final Color, Gain of Color Level Values, and Initial and Final Vickers Microhardness

Groups	Initial Shade	Final Shade	Shade Ranking Mean	Shade (p)	Initial VHN	Final VHN	VHN (p)
WL	11.43 (B3)	4.23 (D2)	7.20	0.01	303.20	302.27	0.86
WH	11.80 (B3)	3.43 (B2)	8.36	0.01	287.04	290.12	0.55
QL	11.96 (B3)	4.26 (D2)	7.70	0.01	306.16	318.72	0.06
QH	11.90 (B3)	3.56 (B2)	8.33	0.01	302.44	301.65	0.90
C	12.40 (A3.5)	12.40 (A3.5)	0	–	307.58	307.58	–

each light source activation time: Nd:YAG laser (100 mJ, 25 Hz and 2.5 W for 2 min) application without whitening agent (control); with Whiteness HP Maxx and with H_2O_2 + carbopol + Q-switch and halogen light application (for 40 s) without whitening agent (control); with Whiteness HP Maxx and with H_2O_2 + carbopol + Q-switch. The same was done with the thermocouple placed in the pulp chamber with the light source on the surface. Three readings were taken to determine a mean temperature for each position.

Statistical Analysis

The Shapiro-Wilk test was performed to determine the normality of the bond strength test results. Next, ANOVA followed by Tukey's test was applied with a confidence level of 95% to determine the differences between the groups.

The microhardness results analysis was performed using the student's *t*-test for paired samples (initial and final).

The Kappa test was primarily used for shade results, to obtain the degree of agreement between the observers considering the hue and then the chrome. Four levels were defined for hue (A, B, C, and D) and 16 levels for chrome. Scores were associated with the color scale used from 1 (B1) to 16 (C4) to determine whether there was color difference after bleaching in comparison with the control, using the student's *t*-test.

RESULTS

The mean initial and final shade for each group presented statistical difference for student's *t*-test ($p < 0.05$) (Table II) indicating that all the whitening protocols performed were efficient. The interobservers Kappa were 42% for initial evaluation and 56% for final evaluation when considering the hue; for chrome it was 22% for the initial evaluation and 50% for the final.

The Vickers microhardness test showed no statistical difference among all the experimental groups (Table IV).

Table V shows the differences among the groups by the Tukey test ($p > 0.05$). The highest mean tensile bond strength was obtained in group 4 (Q-switch + halogen + Single Bond), which was statistically different from group 9 (Q-switch + halogen + Solobond), which presented the lowest mean bond strength.

All the groups that received whitening treatment showed no statistical difference from their control groups (groups 5 and 10).

As regards failure mode (Figure 1), only groups 4 (QHB) and 6 (WLS) showed cohesive in enamel failure. The most common failure mode was the mixed (Figure 2).

The dye absorbance peaks present in the Whiteness HP Maxx thickener were between 252 and 510 nm, whereas the absorbance peaks of the Q-switch dye were between 924 and 1036 nm (Figures 3 and 4).

When considering the kinetics of Whiteness HP Maxx thickener with its 35% hydrogen peroxide (Figure 5), having the wavelength of 332 and 508 nm as parameters, it was observed that after 5 min almost all the dye had reacted with the hydrogen peroxide. The same occurred in the kinetic assay with the Q-switch dye and hydrogen peroxide, having the wavelength of 922 and 1062 nm as parameter, in which almost all the dye had reacted with the hydrogen peroxide after 9 min (Figure 6).

TABLE V. Mean Tensile Bond Strength (MPa) of the Groups

Group	Mean (MPa)	Statistical Difference	Standard Deviation (SD)
4 (QHB)	36.07	A	15.51
2 (WHB)	32.83	AB	7.73
1 (WLB)	32.14	AB	12.87
7 (WHS)	31.62	AB	14.24
10 (CS)	31.37	AB	6.43
5 (CB)	30.76	AB	12.10
6 (WLS)	29.11	AB	9.39
8 (QLS)	28.24	AB	14.49
3 (QLB)	24.96	AB	10.20
9 (QHS)	20.18	B	8.14

Means followed by the same letters show no statistical difference by Tukey ($p < 0.05$).

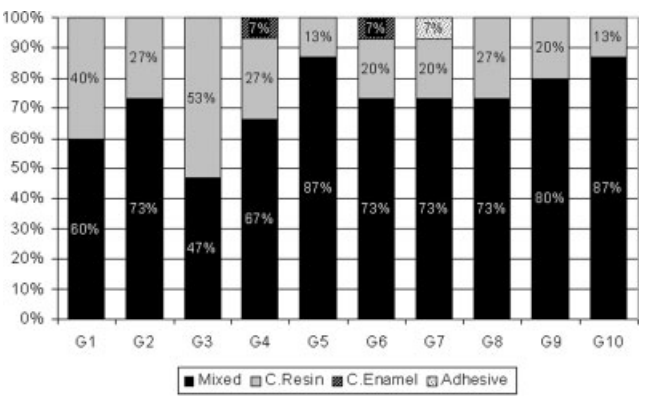

Figure 1. Failure analysis graph. C.Resin = cohesive in composite resin; C.Enamel = cohesive in enamel.

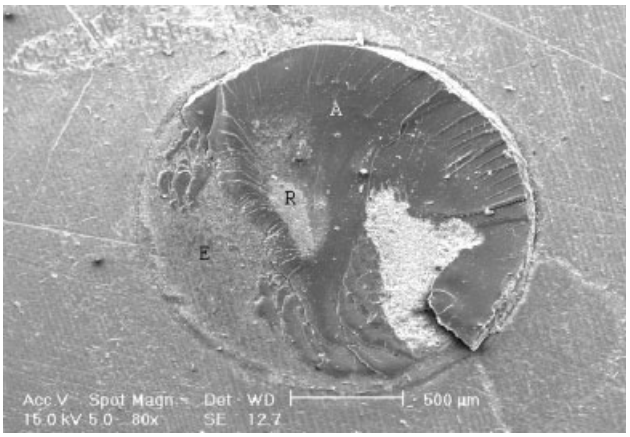

Figure 2. Representative SEM image of mixed failure, the predominant failure pattern observed (R = composite resin; E = enamel; A = adhesive). The large area of adhesive bonded to enamel indicates a stronger bond to the dental tissue.

As shown in Table VI, the temperature generated either by the halogen light or by the Nd:YAG laser was greater on the surface than in the pulp chamber. When the Nd:YAG laser was associated with the whitening agent, the surface temperature decreased and a 7.8°C decrease in the pulp chamber temperature could be observed when using H_2O_2+ carbopol + Q-switch, and 6.8°C when using Whiteness HP Maxx.

When the temperature in the pulp chamber with the use of the halogen light without bleaching agent was compared with the temperature when Whiteness HP Maxx was used, an increase of 1.53°C could be observed.

None of the temperature recorded in the pulp chamber was higher than the body temperature of 37°C.

DISCUSSION

The right time for restoring a tooth after bleaching is still a point to be discussed. Some authors, such as Cavalli et al.[12] reported a decrease in bond strength of bleached teeth, however, the restorative treatments for microtensile

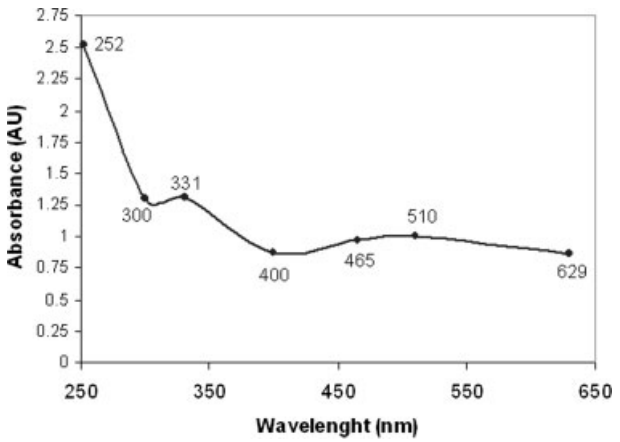

Figure 3. H_2O_2 + thickener absorbance graph (absorbance × wavelength).

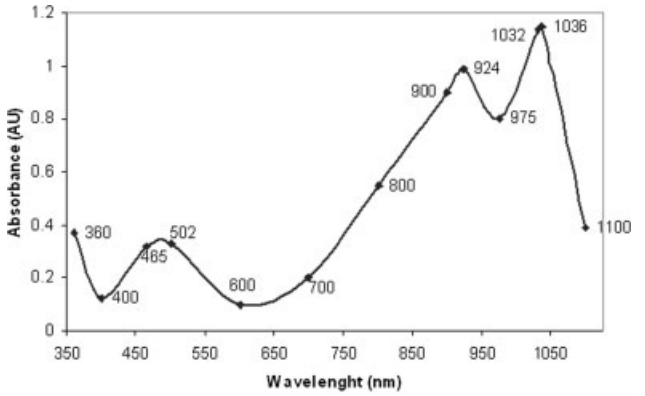

Figure 4. H_2O_2 + carbopol + Q-switch dye absorbance graph (absorbance × wavelength).

testing were performed 24 h after the whitening procedure. El-din et al.[13] observed that bleached teeth presented smaller and thinner resin tags than nonbleached teeth, but the adhesive procedures were performed immediately after the whitening protocols. Whereas Sung et al.[3] reported no statistical significance in the bond strength of bleached teeth that were stored in physiological solution for 5 days before bonding procedures. Gianinni[14] reported that when the specimens exposed to carbamide peroxide were stored in artificial saliva for more than 2 weeks, they were able to release the peroxide absorbed by the enamel during the whitening treatment and re-mineralize it, thus re-establishing its surface morphology.

In the present study there was no statistical difference between the tensile bond strength of bleached groups and their respective controls with both adhesive systems. The storage time after bleaching could be factor responsible for these results. The results of Sung et al.[3] and Gianinni[14] are in agreement with findings of the present study, in which the teeth were stored in artificial saliva for 2 weeks after bleaching, and then the specimens were submitted to the tensile bond strength test. Similar results in dentin were found by Elkhatib et al.[15] who evaluated the tensile bond strength with a self-etching adhesive system. The bleached specimens that were stored in artificial saliva for a week showed no statistical difference when compared with the control group.

The mean bond strengths of groups 4 (QHB) and 9 (QHS) presented statistical difference ($p > 0.01$); however, these higher and lower bond strength values are not related

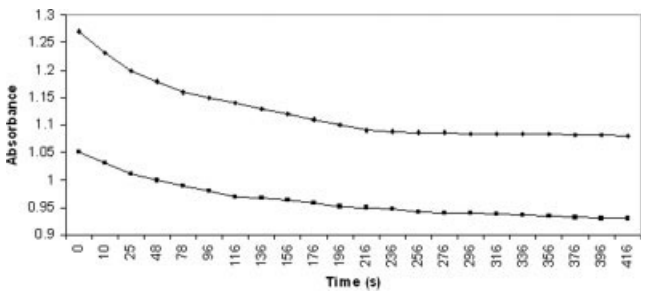

Figure 5. Thickener kinetic testing graph [absorbance × time (s)].

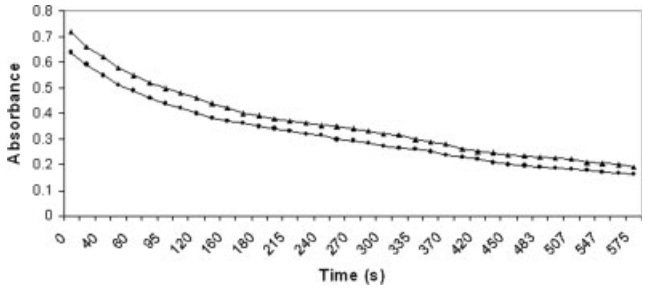

Figure 6. Q-switch dye kinetic testing graph [absorbance × time (s)].

to the whitening treatment itself, since both groups received the same bleaching protocol, and when compared with their control groups, no statistical difference was found. A relevant observation is the trend towards lower bond strength values in the groups treated with the Solobond M adhesive system, which contains acetone in its composition. This finding is in agreement with Sung et al.[3] who compared the bleached enamel bond strength of acetone-based adhesive and ethanol-based systems, and reported lower bond strength values in the groups that received the acetone-based adhesive system. The authors suggested that the ethanol-based adhesive systems interact with the residual oxygen making them capable of minimizing or inhibiting the effects of the bleaching process, particularly when the restorative treatment is performed right after the whitening procedure.

The most common failure mode was the mixed one (adhesive and cohesive in enamel and/or composite resin), since no bond strength and failure mode standardization was observed (Figure 2), which corroborates the findings of El-din et al.[13] who did not find a correlation between the failure mode and the bond strength value. Group 8 (QL) also presented a high percentage of mixed failures (80%), indicating an adequate interaction of the adhesive system with the substrate.

The Vickers microhardness results showed no statistical difference before and after the whitening treatments, but some groups (WH and QL) showed an increase in the final VHN. It is believed that the artificial saliva storage played an important role in these results, which is in agreement with Teixeira et al.[16] who found no statistical differences between the bleached and control groups after 14 days of storage in artificial saliva, both in the enamel surface and the sub-surface. Cesar et al.,[17] who also used artificial saliva to store the 35% hydrogen peroxide and argon laser/halogen light bleached specimens, found no differences in the initial and final VHN. Although Lewinstein et al.[18] observed a decrease in enamel microhardness right after the whitening treatment; they noted that immersing the specimens in fluoride re-established the enamel and the dentin microhardness.

The results obtained by the surface and pulp chamber temperature measurements revealed that the use of whitening agents, irrespective of the light source, transmitted less heat to the pulp. Table VI shows that the highest temperature increase (41.6°C) was obtained with the use of Nd:YAG laser without bleaching agent. Sulieman et al.[19] affirm that when the peroxide and water evaporate, they produce a refreshing effect. Moreover, Sulieman et al.[20] explained that the temperature decrease in the pulp chamber also occurs because of the coefficient of thermal conductibility (1.36×10^{-3} cal sec^{-1} cm^{-2}) of dentin; it means that the reason for heat transmission is related to the dentin thickness. Moreover, the interaction between the light sources and the dyes played a major role in the pulp temperature decrease. Nevertheless, it can be observed that when the Nd:YAG laser was irradiated with the bleaching agent H_2O_2 + carbopol + Q-switch, the temperature that reached the pulp chamber was lower than the temperature that reached it with the use of Whiteness HP Maxx. This seemed to occur because the Q-switch dye, which has an absorbance of 1062 nm, absorbed the laser energy of 1064 nm, and a surface temperature increase occurred even in the deepest parts of the dental structure.

Thus, Joiner,[21] Buchalla and Attin,[22] Sulieman et al.,[19] Ziemba et al.[23] Wetter et al.,[24] Wetter et al.,[25] Luk et al.[5] agree with the relevance of the light emitting equipment, such as the different laser types, having to be used with dental bleaching agents that contain dyes with wavelengths similar to theirs, particularly when considering the pulp heat transmission, because when the dye absorbs the light source energy, it increases the gel temperature and transmits less heat to the deepest dental structures.

The irradiation intensity and the exposure time of the light source on the tooth are very relevant, since the critical temperature that leads to irreversible pulp damage is ≥5.6°C above the body temperature, according to Zach and Cohen.[26] Luk et al.[5] used infrared laser (2.8–3.2 W) and carbon dioxide laser (CO_2, 600 mW) for 3 min and detected pulp temperature values with potential risk, with and increase of 21.67 and 16.55°C, respectively, in the pulp chamber. Whereas, Sulieman et al.[20] when using diode laser (3W) for 30 s, reported an increase of 11.6°C. Gaspar,[27] when using diode laser at 1.6 W of continued pulse, also for 30 s,

TABLE VI. Surface and Pulp Chamber Temperature Measurements With Halogen Light and Nd:YAG Laser Radiation

Light Source	Room Temperature	Localization	Control (Without Whitening Agent) (°C)	H_2O_2 + Thickener (°C)	H_2O_2 + Carbopol + Q-switch (°C)
Halogen	23°C	Surface	32	32.5	35.2
		Pulp chamber	25.8	27.3	24.9
Nd:YAG	23°C	Surface	41.6	38.4	37.6
		Pulp chamber	37.4	31.6	29.8

observed an increase of 10.5°C; and Wetter et al.[25] using diode laser at 2W for 60 s, observed an increase of 12°C. Nevertheless, the pulp chamber temperature results measured when using the Nd:YAG laser for both whitening agents used, were considered safe since they did not raise the temperature above 5.6°C of the body temperature.

All the whitening protocols performed in this research, in addition to being safe when considering the temperature, were also efficient. The results of the present study showed a mean change of seven shade levels for the laser irradiated groups and of eight levels for the halogen light irradiated group, however, indicating no relevant difference in shade alteration among the groups, but statistical difference between the mean shade before and after bleaching for each group. It is important to note that these similar shade alterations were obtained at different times; this means that the total whitening time with laser was approximately 4 min for each tooth and with the halogen light it was approximately 22 min.

The Q-switch dye kinetic study revealed that it is not an inert dye, because as seen in Figure 6, it reacts with the 35% hydrogen peroxide, which suggests that this interaction may form free radicals that can act on the chromophores present in the enamel surface.

Future clinical researches are necessary to confirm the findings about the efficiency of the H_2O_2 + carbopol + Q-switch associated with the Nd:YAG laser, considering the standard alterations to the enamel surface and assessment of the possible adverse effects, such as the degree of dentinal sensitivity and gingival inflammation, which are reported for most of the bleaching techniques.

In conclusion, after bleaching the enamel with Nd:YAG laser there was alteration in enamel shade in comparison with the shade of enamel not submitted to the whitening procedure, being rejected the initial null hypothesis. The shade observed in lased groups was similar to that obtained with the traditional halogen light protocol. The Vickers microhardness and bond strength values were not altered when compared with those of the nonbleached enamel, accepting the null hypothesis. The surface temperatures during the procedure with laser did not exceed 42°C, accepting the null hypothesis.

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