In vitro evaluation of visible light-activated titanium dioxide photocatalysis for in-office dental bleaching

Marla CUPPINI¹, Vicente Castelo Branco LEITUNE¹, Marcela de SOUZA¹, Annelise Kopp ALVES², Susana Maria Werner SAMUEL¹ and Fabrício Mezzomo COLLARES¹

¹ Department of Conservative Dentistry, Dental Materials Laboratory, School of Dentistry, Universidade Federal do Rio Grande do Sul, Rua Ramiro Barcelos 2492, Porto Alegre, Rio Grande do Sul 90035-003, Brazil

² Department of Materials, Ceramic Materials Laboratory, School of Engineering, Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul 90035-003, Brazil

Corresponding author, Fabrício Mezzomo COLLARES; E-mail: fabricao.collares@ufrgs.br

The evaluation of the photocatalysis of visible light activated titanium dioxide employed in hydrogen peroxide (H_2O_2) was carried using seven H_2O_2 solutions (3.5 and 35%) and/or methylene blue (MB), with or without light irradiation (LI); the absorbance of MB was the bleaching indicator. Color analysis was performed on bovine teeth ($n=12$) using two different concentrations of H_2O_2 , 6 and 35% associated with titanium dioxide (TiO_2). Data were analyzed with one and two-way ANOVA, and significance level of $p<0.05$. Solutions containing MB, H_2O_2 at 3.5 or 35%, and TiO_2 , followed by LI, showed significant difference when compared with other groups. Greater MB reduction was found in 35% concentration. H_2O_2 35%+ TiO_2 gel showed no difference in comparison to control group. All groups for the color analysis assay showed ΔE higher than 3.3. In conclusion, TiO_2 and H_2O_2 association is a promisor alternative for reducing the clinical time of in-office dental bleaching.

Keywords: Tooth bleaching, Hydrogen peroxide, Titanium dioxide

INTRODUCTION

Tooth bleaching is considered one of the most important dentistry treatments for patient satisfaction¹. Patient's demand for both healthy and esthetically appearance has rapidly grown in recent years². The esthetics of whiter teeth cause direct impact on smiling³, laughing and also have been linked to social competence, intellectual ability, successful interpersonal relationships and even to psychological stability^{1,2}. Gathering this information, esthetic dentistry has focused its attention on bleaching, and a series of techniques and materials are constantly developed for this purpose.

The success of in-office tooth whitening relies mainly on hydrogen peroxide (H_2O_2) concentration and application period^{4,5}. The home bleaching typically contains lower concentration of H_2O_2 and greater contact time when compared to in-office bleaching products, which generally contains higher concentrations of H_2O_2 (20–38%) with shorter gel-contact periods^{4,5}. Another gel utilized for home bleaching is the carbamide peroxide, a systematic review comparing the H_2O_2 and carbamide peroxide showed the color change in shade guide units (SGU) and ΔE , the tray-delivered carbamide peroxide gels have a slightly better whitening efficacy than H_2O_2 -based products in terms of ΔE , although, the result should be interpreted with caution as the data of ΔSGU did not show statistical difference between the products⁶. In-office bleaching has advantages in terms of professional control, avoidance of material ingestion, possibility of

faster results and treatment time reduction⁷.

Different light sources have been used in association with in-office bleaching agents, to accelerate the chemical reaction rates of the tooth bleaching process. The literature reports activation of bleaching agents by light using halogen, light emitting diode (LED) or laser^{8,9}. Light activated bleaching procedures leads to an increase in hydroxyl radicals release through the rise in temperature⁹. However, the increase in heat may cause irreversible damage to pulpal tissues^{9,10}. The effectiveness of light sources for in-office bleaching has been controversial, and its contribution to commonly used bleaching procedures remains unknown^{11–13}.

Apart from the effect of light sources on accelerating the chemical reaction of bleaching gels, some researches have been made into catalyzing molecules such as titanium dioxide (TiO_2), which it is known to be an important photocatalyst semiconductor in a wide range of environmental applications¹⁴. In order to provide faster results on bleaching, TiO_2 is a great photocatalyst agent option due to its oxidizing properties, absence of toxicity, photo and chemical stability in a wide pH band^{14–16}. The energy of its band gap is +3.2 eV for anatase phase, and therefore, absorbs ultraviolet light (388 nm wavelength), producing oxygen and hydroxyl radicals¹⁷. Nevertheless, TiO_2 has also shown to react at visible light exposure of 400 nm vicinity, which is the same wavelength of common light sources used in dental light curing units¹⁸, probably due to the rutile polymorph phase. One of the most studied TiO_2 for catalysis use is known as AEROXIDE® TiO_2 P25 (Evonik Industries, Essen, Germany), and it consists in a highly dispersed

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Jun 20, 2017; Accepted Apr 1, 2018

doi:10.4012/dmj.2017-199 JOI JST.JSTAGE/dmj/2017-199

powder composed by a mixture of 80% of anatase and 20% of rutile, with a surface area of $50 \text{ m}^2\text{g}^{-1}$ and an average particle size of 21 nm.

In this way, low concentrations of H_2O_2 gels containing TiO_2 have recently been introduced for in-office tooth bleaching, yet, the bleaching protocol for different H_2O_2 concentrations and TiO_2 proportion are not well defined^{18,19}. The challenge is to achieve effectiveness with lower concentrations of H_2O_2 , reducing the adverse effects, such as dentin and gingival sensitivity, and chair time. Based on this background, the objective of this study was to evaluate the photocatalyst effects of visible light activated (VLA) TiO_2 and if the addition of TiO_2 in low and high H_2O_2 concentrations gels can reduce the contact time application. The null hypothesis is that the addition of TiO_2 would not accelerate the bleaching process among different concentrations of H_2O_2 gel.

MATERIALS AND METHODS

Photocatalytic analysis

Seven experimental solutions were prepared by mixing H_2O_2 with/without 10 mg of TiO_2 AEROXIDE® P25 (Evonik Industries) with an aqueous solution of methylene blue dye 20 ppm (Sigma Aldrich Chemical, St. Louis, MO, USA), according to Table 1. The bleaching gel utilized was H_2O_2 -based in two different concentrations: 35 and 3.5% (Whiteness HP, FGM, Joinville, Brazil). Other components of the gel are neutralizing agents, glycol and deionized water. For each group, the solutions were developed separately, and a volume of 4 mL was poured into a quartz cell recipient. The mix ratio for the methylene blue was 4 mg/4 mL and for the bleaching gel, to each 4.96 g it was added 10 mg of TiO_2 in experimental groups.

The visible light-curing unit employed in this study was Radian Cal-LED unit, $1,200 \text{ mW/cm}^2$, 440–480 nm wavelength (Radian Cal, SDI, Bayswater, Australia). An aluminum foil wrapped each quartz cell and the solutions were light irradiated (LI) with continuous irradiance for 5 min on the top of each quartz cell. During light irradiation, the solution was stirred using a magnetic stirrer (Jintan Medical Instrument Factory, Jiangsu, China). After light activation, the aluminum foil was

removed, and the quartz cell was left undisturbed for 10 min, totaling 15 min of action. This process was repeated three times ($n=3$). The LED unit intensity was verified prior each utilization (ECEL Radiometer, Ribeirão Preto, Brazil).

For the absorbance analysis, TiO_2 was removed using a filter ($0.21 \mu\text{m}$) coupled with a syringe and the solutions were placed into another cell. The absorbance at 660 nm was measured using a spectrophotometer (Agilent, Santa Clara, CA, USA) to determine MB concentration, as an indicator of the bleaching effect. In the experimental solutions, the remaining MB concentrations were determined by the absorbance of the experimental solution (A_s) compared with a pure MB solution (A_c), according to the following equation:

$$C = \frac{A_s}{A_c} \times 100$$

C =Concentration of MB after irradiation

A_s =absorbance of experimental solution after irradiation.

A_c =absorbance of pure solution MB 20 ppm (control group) before irradiation.

After the tests using MB organic dye, this study evaluated the behavior of TiO_2 when added to bleaching products currently marketed.

Teeth color change analysis

Thirty-six extracted bovine incisors were used in this study. The crowns were separated from the roots using a diamond disc and cleaned by removing the remnant soft tissue with a scalpel. Pulpal tissue was also removed. A stain solution was prepared by coffee immersion (100 g, Mellita, Avaré, Brazil) in 1 L of boiling water. After cooling, specimens were immersed into the solution and stored in a refrigerator for 7 days at 4°C . After removing from the solution, the specimens were rinsed, dried, and stored in distilled water at 4°C . Labial surfaces were covered with a masking tape containing a 6 mm-diameter fitting the spectrophotometer's scanner (CM2600 Konica Minolta, Osaka, Japan). This procedure ensured measuring the same area at each step.

The specimens were randomly assigned into three groups ($n=12$) and the bleaching gel was applied at the experimental surface using a disposable brush. After

Table 1 Formulations of the experimental solutions (sol) for H_2O_2 at 35% and 3.5%

Solution	MB	H_2O_2	TiO_2	Light Activation
SolMB	X	—	—	—
SolMB+ H_2O_2	X	X	—	—
SolMB+ H_2O_2 +LA	X	X	—	X
SolMB+ TiO_2	X	—	X	—
SolMB+ TiO_2 +LA	X	—	X	X
SolMB+ H_2O_2 + TiO_2	X	X	X	—
SolMB+ H_2O_2 + TiO_2 +LA	X	X	X	X

treatment time, the bleaching gel was removed using damp gauze. The specimens were washed thoroughly under tap water and gently dried. The three groups were: Group H₂O₂ 35%: office-bleaching agent H₂O₂ at 35% without TiO₂ addition (control). Each tooth was light activated with continuous irradiance for 5 min and the bleaching agent was left on the specimens for further 40 min, totaling 45 min of gel action, according to the manufacturer's instructions. Group H₂O₂ 35%+TiO₂: office-bleaching agent H₂O₂ at 35% with the addition of 10 mg of TiO₂. Each tooth was light activated with continuous irradiance for 5 min and the bleaching agent was left on the specimens for a further 10 min, totaling 15 min of gel action. Group H₂O₂ 6%+TiO₂: home-bleaching agent H₂O₂-based at 6%, potassium nitrate and sodium fluoride are desensitizers of the gel (White Class, FGM) with the addition of 10 mg of TiO₂. Each tooth was light activated with continuous irradiance for 5 min and the bleaching agent was left on the specimens for a further 10 min, totaling 15 min of gel action. The final concentration of the bleaching gel was 0.2%, since to each 4.96 g it was added 10 mg of TiO₂ in experimental groups.

As baseline data, the teeth surfaces were recorded prior to bleaching (L_{initial} , a_{initial} and b_{initial}). Bleaching treatments and measurements were subsequently repeated 3 times on the specimens, with one-week intervals, which the samples were stored in distilled water. Each color measurement was carried out 24 h after the bleaching treatment (L_{final} , a_{final} and b_{final}). The color evaluation was obtained from labial surfaces using a spectrophotometer.

The CIE $L^*a^*b^*$ values were assessed using the CIELAB (Commission Internationale L'Eclairage) color coordinate system, where L^* defines lightness, a^* denotes the red/green axis, and b^* denotes the yellow/blue axis. ΔL values indicate if the sample is lighter than the standard (baseline readout), with negative values indicating that the sample is darker or positive values for brighter measurements. Given ΔL , Δa , and Δb , the total difference or distance on the CIELAB diagram

can be stated as a single value, known as ΔE . The color difference (ΔE) was calculated according to the following equation: $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$, where ΔE is the color change; $\Delta L = L_{\text{final}} - L_{\text{initial}}$; $\Delta a = a_{\text{final}} - a_{\text{initial}}$; $\Delta b = b_{\text{final}} - b_{\text{initial}}$.

Statistical analysis

For the data analysis, mean and standard deviation were calculated for each experimental solution. To evaluate the solutions containing TiO₂ photocatalysis using MB, a two-way ANOVA test was applied (H₂O₂ concentration and TiO₂ association). The color difference data (ΔE) of bovine model groups was subjected to statistical analysis with the one-way ANOVA test. Holm-Sidak test was used as a *post hoc* test for multiple comparisons in both analyses. The statistical analysis was performed at 5% level of significance.

RESULTS

The absorbance values for the seven experimental solutions are shown in Table 2. H₂O₂ at 35% concentration, without TiO₂ and no light irradiation, showed a statistically significant difference to the same solution where light exposure was present (SolMB+H₂O₂ and SolMB+H₂O₂+LI) resulting in great decrease when LI was present. Otherwise, the H₂O₂ at 3.5% concentration without TiO₂ and no light irradiation showed no difference compared to the same solution with light application. The solutions that comprised only MB and TiO₂, showed decrease in MB concentration, regardless the light activation or not. When H₂O₂, TiO₂ and light irradiation were associated (SolMB+H₂O₂+TiO₂+LI), the lowest values of MB concentration in both H₂O₂ concentrations was revealed. The association between H₂O₂ and TiO₂ also showed a MB decrease even without light exposure (SolMB+H₂O₂+TiO₂). The solutions of H₂O₂ at 35% concentration resulted in the most reduction in MB; however 3.5% with the addition of TiO₂ also decreased significantly MB concentration.

ΔE mean and standard deviation of experimental bovine teeth groups are shown in Fig. 1D. The H₂O₂

Table 2 Changes in MB concentration (ppm) at each H₂O₂ solution

Solution	35% Mean (SD)	3.5% Mean (SD)
SolMB	100 (0) Aa	100 (0) Aa
SolMB+H ₂ O ₂	30.46 (1.8) Cb	80.95 (3.4) Ba
SolMB+H ₂ O ₂ +LI	20.67 (1.7) Db	80.07 (3.8) Ba
SolMB+TiO ₂	90.25 (2.3) Ba	90.04 (1.3) Ca
SolMB+TiO ₂ +LI	90.06 (1.7) Ba	90 (2.5) Ca
SolMB+H ₂ O ₂ +TiO ₂	9.5 (1.6) Eb	18.5 (3.8) Da
SolMB+H ₂ O ₂ +TiO ₂ +LI	2 (1.0) Fb	12.8 (2.3) Da

Different capital letters indicate statistical difference in the same columns.

Different small letters indicate statistical difference in the same line, $p < 0.05$.

*SolMB: methylene blue solution; H₂O₂: hydrogen peroxide; TiO₂: titanium dioxide; LI: light irradiance.

Fig. 1 A) The mean ΔL , Δa , and Δb , values of H₂O₂ 35% group. B) The mean ΔL , Δa , and Δb , values of H₂O₂ 35%+TiO₂. C) The mean ΔL , Δa , and Δb , values of H₂O₂ 6%+TiO₂ group. D) ΔE value of each experimental group. (G1: H₂O₂ 35%, G2: H₂O₂ 35%+TiO₂, G3: H₂O₂ 6%+TiO₂)

35% group, without TiO₂ and with a major application time did not show statistical significant difference in comparison with H₂O₂ 35%+TiO₂. However, when H₂O₂ concentration was reduced (H₂O₂ 6%+TiO₂), a statistically significant difference was found. The groups containing TiO₂ did not show a statistically significant difference in ΔE , despite the two different H₂O₂ concentrations. ΔL , Δa , and Δb values of each application in each group are shown in Fig. 1. After bleaching treatment, ΔL and ΔE values gradually increased in all groups, while Δa and Δb showed a progressive decrease.

Ascending order of ΔE is shown in Fig. 1D. Among the three bleaching applications, two applications of H₂O₂ 35% gel were enough to produce a bleaching effect. The H₂O₂ 6%+TiO₂ group also did not show a statistically significant difference in final bleaching effect, despite showing a lowest ΔE value. Nevertheless, a third gel application appears to be an important factor in terms of the reduction in time application for H₂O₂ 35%+TiO₂ group.

DISCUSSION

This *in vitro* study evaluated the effects of VLA TiO₂ photocatalyst on bleaching using different

methodologies. H₂O₂ acts as a strong oxidizing agent through the formation of free radicals, reactive oxygen molecules and H₂O₂ anions^{4,7}. The presence of free radicals acts upon chromophore molecules, degrading it into smaller soluble molecules and as consequence of this degradation, there is a reduction in chroma concentration and chromatogens from the tooth^{18,20}.

Since variances such as enamel thickness, extent of bleaching agent penetration and initial tooth color can interfere in results, hematoporphyrin or β -carotene substituting *in vitro* tooth models, were used in one study¹⁹. Similarly, in this study, sample solutions were used with no teeth; so proper evaluations could be realized with minimal variation and better reproducibility. To identify the bleaching effects, methylene blue decomposition was determined through the absorbance of the experimental solutions, as described in previous studies^{18,21,22}. In experimental solutions containing only TiO₂, there were minimal changes in bleaching results. In other hand, association between H₂O₂ and TiO₂ showed MB decreased even without light irradiation. According to some researchers¹⁸, during this association it was likely that either H₂O₂ or TiO₂ produced less free radicals than a combination of both the components. Additionally,

when these components were light activated, MB concentration greatly decreased (Table 2). Between the two different concentrations of H_2O_2 , 35% resulted in the most significant reduction in MB, yet, despite the lower H_2O_2 concentration for the other experimental group, the bleaching performance of 3.5% with TiO_2 addition was comparable with the higher concentration of H_2O_2 .

Lower concentrations of H_2O_2 (3.5%) and light activation showed no significant difference when compared to the same group without light exposure, otherwise, higher peroxide concentrations revealed that when the solution was light irradiated a significant difference was found (SolMB+ H_2O_2 and SolMB+ H_2O_2 +Light Irradiation). As a consequence of light activation, a release of hydroxyl-radicals from higher concentrations of H_2O_2 may be possible through direct excitation by light (photolysis), which induces the molecular vibration and peroxide degradation^{9,20}. As an effect of peroxide degradation, a rise in temperature might cause damage to adjacent soft tissues and pulp^{9,18}, the temperature increase of 5.5°C or higher is considered as a critical value, which should not be exceeded to avoid irreversible pulp damage^{23,24}. To date, the majority of the studies focused on testing the effects of various light sources on bleaching action¹⁸⁻²⁰. This study utilized only the LED-curing unit (440 to 480 nm) to analyze TiO_2 absorption in the visible light region. Although the increase in temperature was not measured, previous studies relate that the heating of materials irradiated by LED is expected to be minimal, inducing less thermal injury when compared to halogen or plasma arc units²⁵⁻²⁷.

To obtain a VLA photocatalysis, most times the TiO_2 require chemical modifications, such as the addition of metals to its composition. However, controlling the TiO_2 morphology has demonstrated to enhance its overall efficiencies²⁸. The mixing of a more active phase (anatase) with a comparatively inactive phase (rutile) could produce a synergistic effect in enhancing the photocatalytic activity^{29,30}. The rutile phase also gives the P25 TiO_2 an enhanced mesoporosity. The intimate contact between two polymorphs might be sufficient to improve the separation of photogenerated electrons and holes, resulting in the high photocatalytic activity of TiO_2 ³¹. The conduction band potential of rutile is more positive than that of anatase (3.0 eV) which means that the rutile phase may act as an electron sink for photogenerated electrons from the conduction band of the anatase phase, as the catalytic activity may be a combined effect of the pore size, the pore size distribution and the appropriate crystal plane on which adsorption takes place²⁸. Regarding the limitations of the experiment, the results for the solutions that comprised both H_2O_2 and a TiO_2 photocatalyst could be more efficacious for tooth whitening than either one alone.

In this study, the behavior of TiO_2 added to bleaching gel products currently marketed was demonstrated in bovine tooth model. Low H_2O_2 concentrations gels catalyzed by TiO_2 have been extensively studied due to concerns of cellular damage to pulp cells, hypersensitivity³ and the caustic nature of the typical

higher concentrations of H_2O_2 bleaching gel (H_2O_2 35%)²³. Different gel concentrations and contact time were tested in this study, it was evaluated if lower concentrations are suitable for acceptable bleaching results and if shorter periods are as effective as the ones recommended by the manufacturers. The decision to analyze two different bleaching duration (15 and 45 min) was determined by a pilot study (data not shown), which tested the bleaching application in 3 different periods: 5, 10 and 15 min. Only for the group with 15 min of bleaching gel action there was an acceptable change of color in ΔE units. Thus, the periods analyzed were: 45 min regarding the manufacturer instructions, and 15 min as experimental subject. Moreover, to simulate tooth discoloration observed clinically, researches have increased the levels of intrinsic tooth color by pre-staining with black tea, coffee, blood or other components^{18-20,32}. In this study, a coffee solution was used to increase the intrinsic tooth color of the bovine teeth.

The concentration of H_2O_2 and contact time are the major factors that determine tooth-bleaching efficacy, and higher H_2O_2 concentration is associated with better results²³. The literature suggests that low concentration of bleaching agent with a longer contact time (home bleaching) is as effective as the in-office bleaching (with a higher concentrated bleaching agent in a shorter period)⁴. In this study, when H_2O_2 concentration and time contact were reduced (H_2O_2 6%+ TiO_2) a significant difference with control group (H_2O_2 35%) was found, showing the reduction of the two factors combined influenced tooth bleaching negatively.

In experimental gels containing both H_2O_2 and TiO_2 , there was no significant difference found in the bleaching outcome, regardless the H_2O_2 concentration. Moreover, the bleaching agents had differences in application time between experimental and control groups, the experimental group containing TiO_2 at 35% H_2O_2 concentration showed no significant difference in ΔE values compare to control group (45 min), thereby, demonstrating that TiO_2 photocatalyst containing gel can accelerate the bleaching process in 30 min. This result shows that the addition of TiO_2 may be an alternative to reduce the clinical time required and lowering the possible adverse effects and dentin sensitivity of longer contact time on tooth surface²⁰. Color readout was performed by spectrophotometry following the CIE $L^*a^*b^*$ system, and 3.3 or higher values of ΔE were considered as an acceptable change of color, according to previous studies^{20,33,34}. The results of the bleaching effectiveness showed that after three applications all groups presented higher ΔE values than 3.3, indicating a clinical change of color in all groups. Bleaching was defined as a change in ΔE units that can be related to an increase in luminosity. Previous clinical studies have often used ΔL to assess changes in the lightness of a tooth^{20,23,34,35}, corroborating with the ΔE values found in this study, the ΔL values gradually increased in all groups.

During the bleaching protocol, two applications were enough to produce a bleaching effect in H_2O_2

35% group and the third application did not show any significance to the final result, as it is shown in some other reports²³⁾. The H₂O₂ 6%+TiO₂ group also showed no significant difference between second and third sessions. Differently, third gel application demonstrated to be an important factor for higher H₂O₂ concentration and reduction in time application (H₂O₂ 35%+TiO₂). The bleaching outcome of this group was only possible to be established after the third gel application. In compliance with these findings, it is possible that bleaching protocol should also consider the number of gel applications as a determining factor of the efficacy in TiO₂ addition.

For some authors, H₂O₂ concentration at 15% is still too high to be considered as a non-irritant material³⁾, evidencing the need for in-office bleaching with lower concentrations of H₂O₂. This study demonstrated that H₂O₂ 6%+TiO₂ group showed a clinical change of teeth color after three applications, which can probably meet the needs of seeking faster bleaching treatment and results regarding dentin sensitivity as a non-irritant material. To corroborate, one study tested the effectiveness of 6% H₂O₂ concentration associated with TiO₂²³⁾. In one side of the hemiarcade they have utilized 35% H₂O₂ and on the other 6% H₂O₂ with nitrogen-doped TiO₂. Results showed both treatments had a change between baseline color, hence that at this design, 6% H₂O₂ is effective for tooth bleaching, reaching good clinical results with less adverse effects. However, this data differs from some reports, which in-office bleaching was tested with 6% H₂O₂/TiO₂-N vs. 35% H₂O₂³⁵⁾. Only for 35% H₂O₂ group the ΔE values were significantly higher after second bleaching session. This fact can be explained due the consideration of 35% H₂O₂ as control group and its bleaching protocol recommended by the manufacturer was used in all groups, which unfortunately reduced the contact time of 6% H₂O₂ for half of the recommended time, lowering significantly the efficacy of in-office bleaching at this concentration.

According to overall results of this study, all groups showed a change from baseline color. Experimental groups containing TiO₂ showed the possibility to reduce the clinical time required in 30 min without compromising the bleaching outcome. The opportunity to reduce by 30 min the clinical time could have great impact on patient's satisfaction, since faster appointments to the dentist office are desired. For the clinician, the impact of reducing time for a procedure can result on more patients' appointments per hour, optimizing the time and possibly lowering the side effects, like in less tooth sensitivity to patients. Further investigations, such as randomized clinical trials, are required to confirm the effectiveness stated for the TiO₂ and H₂O₂ combinations.

CONCLUSIONS

The null hypothesis was rejected; it was concluded that TiO₂ addition was able to actuate on the H₂O₂ bleaching gel performance, regardless the concentration of the gel. The photocatalytic activity demonstrated by TiO₂ on this study indicates a promisor alternative to reduce by 30

min the contact time of the bleaching gel on the enamel surface.

REFERENCES

- 1) Meireles SS, Goettems ML, Dantas RV, Bona AD, Santos IS, Demarco FF. Changes in oral health related quality of life after dental bleaching in a double-blind randomized clinical trial. *J Dent* 2014; 42: 114-121.
- 2) Tin-Oo MM, Saddki N, Hassan N. Factors influencing patient satisfaction with dental appearance and treatments they desire to improve aesthetics. *BMC Oral Health* 2011; 11: 6.
- 3) Martin J, Fernandez E, Bahamondes V, Werner A, Elphick K, Oliveira OB Jr, Moncada G. Dentin hypersensitivity after teeth bleaching with in-office systems. Randomized clinical trial. *Am J Dent* 2013; 26: 10-14.
- 4) Joiner A. The bleaching of teeth: a review of the literature. *J Dent* 2006; 34: 412-419.
- 5) Sulieman M, Addy M, MacDonald E, Rees JS. The effect of hydrogen peroxide concentration on the outcome of tooth whitening: an in vitro study. *J Dent* 2004; 32: 295-299.
- 6) Luque-Martinez I, Reis A, Schroeder M, Munoz MA, Loguercio AD, Masterson D, Maia LC. Comparison of efficacy of tray-delivered carbamide and hydrogen peroxide for at-home bleaching: a systematic review and meta-analysis. *Clin Oral Investig* 2016; 20: 1419-1433.
- 7) Sulieman MA. An overview of tooth-bleaching techniques: chemistry, safety and efficacy. *Periodontol* 2000 2008; 48: 148-169.
- 8) Marson FC, Sensi LG, Vieira LC, Araujo E. Clinical evaluation of in-office dental bleaching treatments with and without the use of light-activation sources. *Oper Dent* 2008; 33: 15-22.
- 9) Buchalla W, Attin T. External bleaching therapy with activation by heat, light or laser—a systematic review. *Dent Mater* 2007; 23: 586-596.
- 10) Klaric E, Rakic M, Sever I, Tarle Z. Temperature rise during experimental light-activated bleaching. *Lasers Med Sci* 2015; 30: 567-576.
- 11) Bernardon JK, Sartori N, Ballarin A, Perdigao J, Lopes GC, Baratieri LN. Clinical performance of vital bleaching techniques. *Oper Dent* 2010; 35: 3-10.
- 12) Alomari Q, El Daraa E. A randomized clinical trial of in-office dental bleaching with or without light activation. *J Contemp Dent Pract* 2010; 11: E017-24.
- 13) Kugel G, Papathanasiou A, Williams AJ 3rd, Anderson C, Ferreira S. Clinical evaluation of chemical and light-activated tooth whitening systems. *Compend Contin Educ Dent* 2006; 27: 54-62.
- 14) Fujishima A, Honda K. Electrochemical photolysis of water at a semiconductor electrode. *Nature* 1972; 238: 37-38.
- 15) Spasiano D, Marotta R, Malato S, Fernandez-Ibañez P, Di Somma I. Solar photocatalysis: Materials, reactors, some commercial, and pre-industrialized applications. A comprehensive approach. *Appl Catal B: Environmental* 2015; 170-171: 90-123.
- 16) Kazuhito H, Hiroshi I, Akira F. TiO₂ Photocatalysis: A historical overview and future prospects. *Jpn J Appl Phys* 2005; 44: 8269.
- 17) Fujishima A, Rao TN, Tryk DA. Titanium dioxide photocatalysis. *J Photochem Photobiol C Photochem Rev* 2000; 1: 1-21.
- 18) Suyama Y, Otsuki M, Ogisu S, Kishikawa R, Tagami J, Ikeda M, Kurata H, Cho T. Effects of light sources and visible light-activated titanium dioxide photocatalyst on bleaching. *Dent Mater J* 2009; 28: 693-699.
- 19) Suemori T, Kato J, Nakazawa T, Akashi G, Igarashi A, Hirai Y, Kumagai Y, Kurata H. Effects of light irradiation on bleaching by a 3.5% hydrogen peroxide solution containing titanium dioxide. *Laser Phys Lett* 2008; 5: 379-383.

- 20) Kishi A, Otsuki M, Sadr A, Ikeda M, Tagami J. Effect of light units on tooth bleaching with visible-light activating titanium dioxide photocatalyst. *Dent Mater J* 2011; 30: 723-729.
- 21) Suemori T, Kato J, Nakazawa T, Akashi G, Hirai Y. A new non-vital tooth bleaching method using titanium dioxide and 3.5% hydrogen peroxide with a 405-nm diode laser or a halogen lamp. *Laser Phys Lett* 2008; 5: 454-459.
- 22) Tatsuma T, Tachibana S-i, Miwa T, Tryk DA, Fujishima A. Remote bleaching of methylene blue by UV-irradiated TiO₂ in the gas phase. *J Phys Chem B* 1999; 103: 8033-8035.
- 23) Martin J, Vildosola P, Bersezio C, Herrera A, Bortolatto J, Saad JR, Oliveira OB Jr, Fernández E. Effectiveness of 6% hydrogen peroxide concentration for tooth bleaching—A double-blind, randomized clinical trial. *J Dent* 2015; 43: 965-972.
- 24) Tano E, Otsuki M, Kato J, Sadr A, Ikeda M, Tagami J. Effects of 405 nm diode laser on titanium oxide bleaching activation. *Photomed Laser Surg* 2012; 30: 648-654.
- 25) Sulieman M, Addy M, Rees JS. Surface and intra-pulpal temperature rises during tooth bleaching: an in vitro study. *Br Dent J* 2005; 199: 37-40; discussion 32.
- 26) Michida SM, Passos SP, Marimoto AR, Garakis MC, de Araujo MA. Intrapulpal temperature variation during bleaching with various activation mechanisms. *J Appl Oral Sci* 2009; 17: 436-439.
- 27) Mondelli RF, Soares AF, Pangrazio EG, Wang L, Ishikiriyama SK, Bombonatti JF. Evaluation of temperature increase during in-office bleaching. *J Appl Oral Sci* 2016; 24: 136-141.
- 28) Pelaez M, Nolan NT, Pillai SC, Seery MK, Falaras P, Kontos AG, Dunlope PSM, Hamiltone JWW, Byrne JA, O'Shea K, Entezari MH, Dionysiou DD. A review on the visible light active titanium dioxide photocatalysts for environmental applications. *Appl Catal B* 2012; 125: 331-349.
- 29) Linsebigler AL, Lu G, Yates JT. Photocatalysis on TiO surfaces: principles, mechanisms, and selected results. *Chem Rev* 1995; 95: 735-758.
- 30) Hurum DC, Gray KA, Rajh T, Thurnauer MC. Recombination pathways in the Degussa P25 formulation of TiO₂: surface versus lattice mechanisms. *J Phys Chem* 2005; 109: 977-980.
- 31) Datye AK, Riegel G, Bolton JR, Huang M, Prairie MR. Microstructural characterization of a fumed titanium dioxide photocatalyst. *J Solid State Chem* 1995; 115: 236-239.
- 32) Pirolo R, Mondelli RF, Correr GM, Gonzaga CC, Furuse AY. Effect of coffee and a cola-based soft drink on the color stability of bleached bovine incisors considering the time elapsed after bleaching. *J Appl Oral Sci* 2014; 22: 534-540.
- 33) Lindsey DT, Wee AG. Perceptibility and acceptability of CIELAB color differences in computer-simulated teeth. *J Dent* 2007; 35: 593-599.
- 34) Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater* 1987; 3: 246-251.
- 35) Bortolatto JF, Trevisan TC, Bernardi PS, Fernandez E, Dovigo LN, Loguercio AD, Batista de Oliveira Jr O, Pretel H. A novel approach for in-office tooth bleaching with 6 % H₂O₂/TiO₂ and LED/laser system—a controlled, triple-blinded, randomized clinical trial. *Lasers Med Sci* 2016; 31: 437-444.