Dental Materials Journal 2023; 42(5): 654–658

Surface and intra-pulpal temperature variation during tooth whitening photoactivated with LED/laser

Joatan Lucas de Sousa Gomes COSTA[1], Mariana Bena GELIO[2], Lucas David GALVANI[2], João Felipe BESEGATO[3], Ester Alves Ferreira BORDINI[4], Eduardo Fernández GODOY[5], Luis Geraldo VAZ[6] and Milton Carlos KUGA[1]

[1] *Department of Restorative Dentistry, School of Dentistry, Federal University of Minas Gerais —UFMG, Belo Horizonte, MG, Brazil*
[2] *Department of Restorative Dentistry, School of Dentistry, São Paulo State University —UNESP, Araraquara, SP, Brazil*
[3] *School of Dentistry, Federal University of Mato Grosso do Sul —UFMS, Campo Grande, MS, Brazil*
[4] *Department of Operative Dentistry, Endodontics and Dental Materials, Bauru School of Dentistry, University of São Paulo —USP, Bauru, SP, Brazil*
[5] *Instituto de Ciencias Biomédicas, Universidad Autónoma de Chile, Santiago, Chile*
[6] *Department of Dental Materials and Prosthodontics, School of Dentistry, São Paulo State University —UNESP, Araraquara, SP, Brazil*
Corresponding author, Joatan Lucas de Sousa Gomes COSTA; E-mail: joatan_costa@hotmail.com

This study evaluated the variation of surface and intra-pulpal temperature, during bleaching protocol, using LED/laser. The 35% (HP35), 15% (HP15) and 6% (HP6) gels were used associated with LED/laser applied every 1 min for 30 min in a human canine. The evaluation of surface temperature variation (ΔTs) was performed using a pHmeter and the intra-pulpal temperature variation (ΔTi) was performed using a digital thermometer, at times of 1-, 5-, 10- 15- and 30-min. Statistical analysis was performed using the two-way repeated measures ANOVA test and Bonferroni *post-hoc* test was used at a significance level of 5%. HP35 and HP15 showed greater temperature variation than HP6 up to 10 min of surface evaluation, showing no differences between them. In the intra-pulpal evaluation, no group showed differences throughout the procedure.

Keywords: Dental bleaching, Hydrogen peroxide, Violet LED, Temperature

INTRODUCTION

The evolution of dentistry has allowed several treatments to be performed in a more conservative way. Tooth whitening emerges as a safe, conservative, and low-cost approach, which allows aesthetics results in a short period. Although tooth whitening has been widely performed in dental offices with good acceptability by patients, it is not yet fully understood which whitening protocol is the safest[1-4].

Currently, the in-office bleaching techniques consist in the use of gels with high concentration of hydrogen peroxide (HP). The mechanism of action over dental enamel structures happens by dissociation of gels into unstable free radicals, that penetrates in the dental structure and react, through oxy-reduction, with substances with long chains of C=C double bonds, named chromophores. After a certain number of specific reactions, the chromophores degrade into saturated C chains with single bonds and begin to reflect more light, resulting in a clearer appearance of the teeth[1-3].

The photoactivation of whitening agents by lasers and/or violet LED sources (405±10 nm) has been proposed to enhance the production of free radicals and their penetrability into dental structure to provide the breaks of staining macromolecules in a time-saving manner[5-7]. The use of light sources in tooth whitening assumes that enamel whitening occurs through the photon energy transmission derived from the light with maximization of gel oxidation[8]. For good interaction it is necessary that the minimum of light is transmitted to the tooth structure. Therefore, manufacturers have introduced products with dyes capable of absorbing light in the visible wavelength that are able to restrict heat to the gel layer and thus transfer energy to the peroxide, stimulating chemical dissociation into free radicals[9-12]. Although the potential of enhance the esthetic efficacy of tooth whitening in a time-saving approach may be interest, the use of light sources has some limitations related with the increase of temperature, which affects the safety of the protocols. For safety use, the heat generation by light-based tooth whitening cannot be harmful to dental tissues and should maintain the pulp vitality. Zach and Cohen[13] stated that an increase in intrapulpal temperature of 5.5ºC is capable of promoting irreversible pulp damage. As this information is limited about the risks/benefits of LED/laser, it is interesting to evaluate the temperature increase in gels with different colors and under a certain set of parameters to establish an adequate and safe light-based tooth whitening.

Therefore, this study evaluated the surface and intrapulpal temperature variations during tooth whitening using gels with different colors and photoactivation violet LED and infrared laser (LED/laser) intermittently over 30 min. The null hypothesis is that the bleaching gels photoactivated by LED/laser do not promote surface and intrapulpal temperature variations in the evaluated periods.

MATERIALS AND METHODS

Specimen preparation

A human lower canine (6 mm labial thickness), extracted for periodontal reasons, free from caries and restorations

Received Feb 2, 2023: Accepted Apr 6, 2023
doi:10.4012/dmj.2023-017 JOI JST.JSTAGE/dmj/2023-017

was used. The remaining periodontal ligament was cleaned with a #15 scalpel blade followed by prophylaxis with pumice stone and water. After that, each tooth was sectioned 2 mm below the cementoenamel junction using a cutting machine (Isomet 1000, Buehler, Lake Bluff, IL, USA). The root canal was enlarged with a diamond bur #2135 (approximately 2 mm to allow the penetration of the thermal sensor) (KG Sorensen, Cotia, Brazil)[14]. The pulpal remains were removed using curettes and the root canal was irrigated with saline solution.

Whitening protocols

The groups were divided according to the concentration of hydrogen peroxide used. Table 1 displays the materials' composition. The whitening gels (Table 1) were handled according to the manufacturer's instructions (available at www.dmcgroup.com.br). Gels of 35% (HP35) and 6% (HP6) concentrations were handled in a ratio of 3:1, between peroxide and thickener (phases 1 and 2). On the other hand, 15% gel (HP15) was handled in a 1:1:1 (phases 1, 2 and 3) ratio, between peroxide, thickener and thinner. After the drops were dispensed, the HP35 and HP15 groups were handled with a plastic spatula, performing circular movements for 10 s, until the color was homogenized. For the HP6 group, the syringes corresponding to phase 1 (HP) and 2 (thickener) were coupled using the luer-lock adapter and 10 back-and-forth motion were performed until color homogenization. Figure 1 shows the appearance of the gels after handling.

A 1-mm layer of gel was placed over the buccal surface of the tooth and the time protocol was standardized on a total of 30 min for all groups evaluated. Violet LED (405±10 nm; 2,400 mW; 600 mW/cm^2) and infrared laser system (810 nm; 300 mW; 600 mW/cm^2) (Whitening light plus, DMC, São Carlos, Brazil) were simultaneously applied every 1 min to photo-accelerate the whitening process. All groups received 15 min of light irradiation and 15 min without irradiation. The distance between the light source and the specimen was 10 mm. Six repetitions were performed in each group (n=6)[14,15].

Surface and intra-pulpal temperature variation

For this analysis, the room temperature was standardized at 25ºC and checked by a thermometer (HM-01, Highmed, São Paulo, Brazil)[16] The evaluation of temperature variations (ΔT) were carried out in 1, 5, 10, 15 and 30 min, after starting the whitening protocol. The surface temperature was evaluated with pHmeter (Apera Instruments, Columbus, OH, USA) with the sensor in contact with the gel, whereas the intra-pulpal temperature evaluation occurred after fill the pulp chamber with thermal paste (Implastec, Votorantim, Brazil), as a heat conductor[14]. After, a thermometer type K sensor (MT 1044, Minipa Ind., São Paulo, Brazil) was

Table 1 Groups, bleaching agents and composition of protocols used in this study

Groups	Product name	Composition
HP35	Lase Peroxide Flex 35% (DMC, São Carlos, Brazil)	Mixture of Phases 1 and 2 (35% hydrogen peroxide): hydrogen peroxide, thicking, nano-particled catalyser (titanium dioxide), neutralizing, annatto and juá dye, chelator agent and purified water
HP15	Lase Peroxide Flex 15% (DMC)	Mixture of Phases 1, 2 and 3 (15% hydrogen peroxide): hydrogen peroxide, thicking, nano-particled catalyser (titanium dioxide), neutralizing, annatto and juá dye, chelator agent and purified water
HP6	Nano White Flex 6% (DMC)	Mixture of Phases 1 and 2 (6% hydrogen peroxide): hydrogen peroxide, thicking, nano-particled catalyser (titanium dioxide), neutralizing, annatto dye, chelator agent and purified water

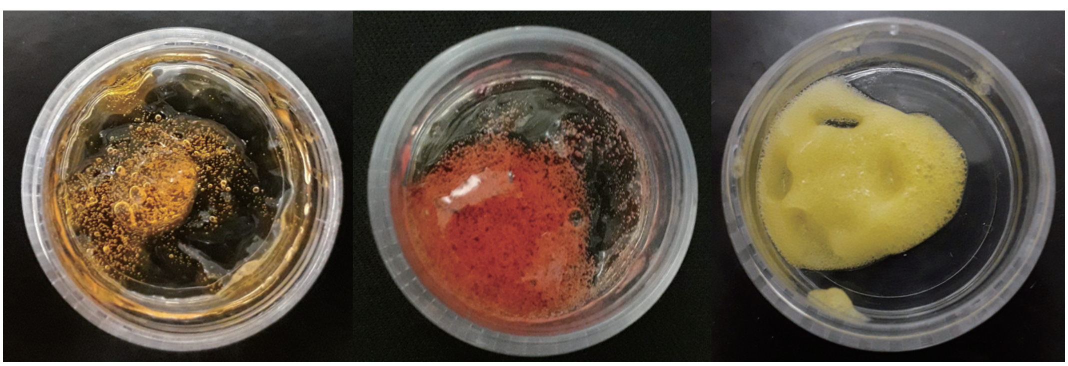

Fig. 1 Gel colors after manipulation: orange (HP35), red (HP15) and yellow (HP6).

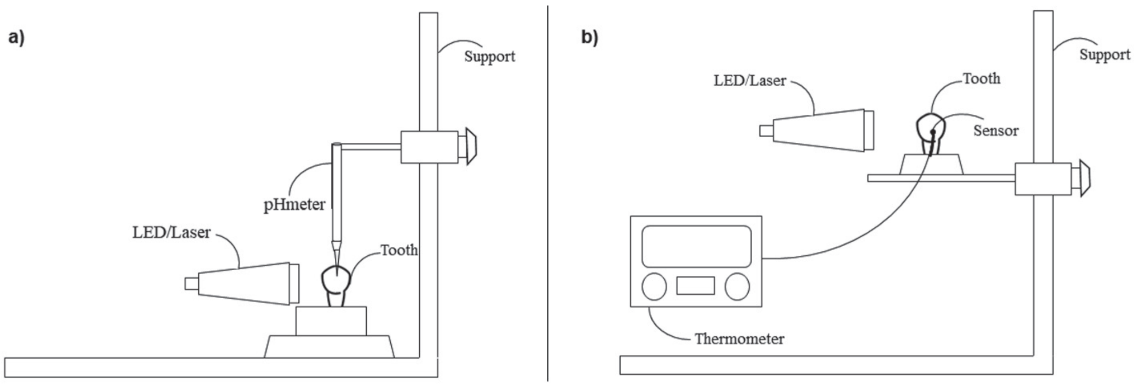

Fig. 2 Schematic drawings: a) Surface analysis; b) Intrapulpal analysis.

Table 2 Mean±standard deviation of Δ*Ts* (temperature increase) according to each evaluation time (*n*=6)

Groups	1 min	5 min	10 min	15 min	30 min
HP35	6.01±0.83^{A}	8.08±0.88^{A}	10.67±1.59^{A}	9.87±0,80^{A}	8.70±1.17^{A}
HP15	5.37±1.46^{A}	7.75±1.90^{A}	10.46±0.78^{A}	9.01±1.25^{AB}	8.23±1.48^{AB}
HP6	1.42±0.44^{B}	3.43±0.67^{B}	6.28±1.03^{B}	7.05±1.34^{B}	6.55±0.70^{B}

Two-way repeated measure ANOVA followed by Bonferroni test (p<0.05).
Different uppercase letters mean statistically significant difference within the same evaluation time for each Δ*.

Table 3 Mean±standard deviation of Δ*Ti* (temperature increase) according to each evaluation time (*n*=6).

Groups	1 min	5 min	10 min	15 min	30 min
HP35	1.98±0.41	2.78±0.79	2.02±0.97	3.13±0,92	1.95±0.92
HP15	1.22±0.35	2.23±0.37	1.13±0.46	2.60±0.46	1.67±0.62
HP6	1.37±0.54	1.87±0.69	1.47±0.72	2.31±0.83	1.87±0.70

Two-way repeated measure ANOVA followed by Bonferroni test (p<0.05).
No differences were found among the groups (p>0.05).

inserted in the center of the pulp chamber (its position was radiographically checked), which remained stable on the surface throughout the procedure (Fig. 2). After the evaluation of each group (*n*=6), the paste was removed and replaced.

Statistical analysis

After verification of data normality by Shapiro-Wilk test (p>0.05), two-way ANOVA for repeated measures followed by Bonferroni *post-hoc* tests. The analyses were performed in IBM® SPSS Statistics® version 22 (IBM, New York City, NY, USA) for the evaluation of surface and intra-pulpal temperature.

RESULTS

The analysis of surface temperature variation (Δ*Ts*) is shown in Table 2. HP35 and HP15 obtained greater pulp temperature variation than HP6 up to 10 min of evaluation using LED/laser (p<0.001). The periods corresponding to 15 and 30 min demonstrated that HP15 was an intermediate group and did not show differences between HP35 and HP6 (p>0.05), however HP35 and HP6 have continued to show statistically significant relationship among these groups.

The evaluation of intrapulpal temperature variation with the use of LED/laser (Δ*Ti*) is shown in Table 3. There were no differences between temperature variations between groups, regardless of the entire evaluation period (p>0.05).

DISCUSSION

This study evaluated the surface (Δ*Ts*) and intrapulpal (Δ*Ti*) temperature variation during tooth whitening using gels with different concentrations and colors photoactivated by LED/laser sources. Δ*Ts* showed a higher temperature increase than Δ*Ti*. The null hypothesis was rejected for Δ*Ts*, since the gels showed significant temperature differences, but was accepted for ΔTi.

It is difficult to obtain precise conclusions about tooth whitening since the results are dependent on several variables and the lack of standardization of protocols is recurrent in related studies. The gels used in this study are part of a new trend that has been implemented in dentistry whom presents in its composition the addition of TiO_2 with nitrogen particles, as a semiconductor[5,17,18]. The interaction of these compounds with blue or violet LED allows the implementation of several protocols. To better understand whether gels promote temperature variation, we standardized the Nano White Flex 6% protocol, that consists of intermittent application of LED/laser every 1 min for 30 min. Since our main outcome was the temperature of the enamel and intra-pulpal surface, only one tooth was used in the tests, in order to avoid variations in enamel and dentin thickness[12,14,15], while the thermal paste used allowed heat transference into the pulp chamber to be measured by the thermometer sensor.

In light-based tooth whitening, the esthetic success depends on the amount of energy absorbed from the light source by the bleaching gel so that the speed of redox reactions is accelerated, as well as the release of hydrogen peroxide free radicals. In this study, violet LED, which has a shorter wavelength and acts on the most superficial layers of the tooth where the whitening gel remains, was associated with infrared laser that activates the gel and increases the mobility of free radicals[19].

The gels used have similar composition. However, in addition to the different concentrations (Table 1), they exhibit distinct final colors and degrees of translucency at the end of handling (Fig. 1). This observation warns about possible different levels of interaction with the LED/laser system. When the light is directed to the gel, not all it is absorbed, and part of the energy may be reflected or refracted in a way that influences the amount of heat generated[12]. It is interesting to mention that the gels have the semiconductor N-doped TiO_2 in their composition. Thus, for adequate activation of their oxidizing properties and maximization of their results, it is paramount that the gel presents good interaction with the LED/laser system for greater conversion into thermal energy[20].

Based on our results, it was observed that the dyes presented in the gels (annatto and juá) are indicative of the peroxide reaction throughout the treatment and as the gel was photo-accelerated. The three groups showed changes in color, from red to orange, in the HP15 group and to a colorless appearance in HP35 and HP6 groups. In addition, it was seen that the HP35 and HP15 groups had greater interaction with the LED/laser system, leading to an increase in surface temperature around 10.5ºC (Table 2). Although it has already been reported[9,10,12] that the incidence of violet light is not complementary to the orange and red colors, it is clear how much higher the values were in relation to HP6 group (yellow), where the temperature peak reached an approximate variation of 7ºC, even with the more opaque appearance of the gel in relation to the other two. However, this lower interaction of the HP6 group with the LED/laser system used does not prevent satisfactory aesthetic results, and the gel is presented as an interesting conservative alternative[5,21,22].

Another important finding observed in Table 2 is the temperature peak reached in 10 min for HP35 and HP15 and at 15 min for HP6 group. We hypothesize that in these time intervals the gels have achieved their maximum light absorption and that, possibly, after conversion to thermal energy, the reactions tend to decrease, as the peak had already been reached. Therefore, HP35 and HP15 are gels that interacted better with the LED/laser system and they are more concentrated, which showed a faster temperature rise than HP6. Studies evaluating the ionic potential and correlating it with the temperature increase, appear as interesting alternatives to elucidate this question and establish whether the bleaching treatment can be interrupted when it reaches its peak of redox reactions

Comparing the surface and intra-pulpal evaluations (Tables 2 and 3), our study corroborates with Sari *et al.*[23] and Sulieman *et al.*[24] which report that the thermal energy produced by the LED/laser is retained on the surface with the gel. According to them, the gel works as a thermal barrier to promote the insulating effect, in order to reduce the temperature on the tooth surface, mainly because it has hydrogen peroxide and water in its composition, and its evaporations promote a cooling effect on the vital pulp. Sulieman *et al.*[24] also state that the presence of whitening gel can reduce the temperature increase by 87 to 96% in relation to the pulp. This temperature reduction was seen in our study, since the groups did not show differences between themselves in any of the moments of intra-pulpal evaluation. In this way, the LED/laser protocol applied intermittently every 1 min was considered safe from a thermal perspective considering the limits of 5.5°C[13] that would be promote irreversible pulp damage.

This study has some limitations related to *in vitro* conditions since the methodology does not present evidence that may influence heat transfer such as humidity promoted by blood circulation and pulpal fluid, as well as the damage caused by the increase in pulp temperature. Currently, the importance of *in vivo* studies is known for more accurate considerations of bleaching research and even knowing that *in vitro* studies will hardly be able to replicate the clinical environment, interesting answers can be obtained with their conclusions. The present bleaching protocols in association with LED/laser are considered safe since they remained within the standards established in the literature and under clinical conditions. In addition to the lower thermal conductivity level, there is still the circulation of pulp fluid and blood circulation that act as heat sinks, protecting the pulp[23,25,26]. Furthermore, these alternative protocols have been shown esthetic efficacy comparable with 35% HP[5,21,27] which can predict good clinical outcomes depending on patient's cooperation.

We emphasize the importance of further studies that address not only the benefits of using LED/laser in tooth whitening, but also the possible risks of its use. It is known that the heat generated from light sources, if transferred indiscriminately to the dental structure, can result in pulp damage, in addition to causing bleaching-related hypersensitivity. It is clear that the good interaction between the gel and the LED/laser system is crucial to the efficacy and safety of light-accelerated protocols. In this way, our study may serves as a rational basis for further experiments.

CONCLUSION

It was concluded that HP35 and HP15, with their orange and red colors respectively, showed better interaction with violet LED and infrared laser, with greater and faster temperature increase than HP6 group, in the yellow color. In addition, the LED/laser applied intermittently proved to be safe regarding the thermal intra-pulpal variation.

ACKNOWLEDGMENTS

The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel, Finance Code 001—Process Number: 88887.464717/2019-00) for the financial support in this study.

CONFLICTS OF INTEREST

The authors have no conflicts of interest in this article.

REFERENCES

1) Kwon SR, Wertz PW. Review of the mechanism of tooth whitening. J Esthet Restor Dent 2015; 27: 240-257.
2) Ubaldini ALM, Baesso ML, Medina Neto A, Sato F, Bento AC, Pascotto RC. Hydrogen peroxide diffusion dynamics in dental tissues. J Dent Res 2013; 92: 661-665.
3) Alqahtani MQ. Tooth-bleaching procedures and their controversial effects: A literature review. Saudi Dent J 2014; 26: 33-46.
4) Bersezio C, Martín J, Angel P, Bottner J, Godoy I, Avalos F, *et al*. Teeth whitening with 6% hydrogen peroxide and its impact on quality of life: 2 years of follow-up. Odontology 2019; 107: 118-125.
5) Costa JL de SG, Besegato JF, Zaniboni JF, Galvani LD, Kuga MC. Effects of tooth bleaching protocols with violet LED and hydrogen peroxide on enamel properties. Photodiagnosis Photodyn Ther 2022; 38: 102733.
6) Mayer-Santos E, Bachiega-Silva B, Twiaschor CV, Shimokawa CAK, Marinho GB, Junior AB, *et al*. Blinded, parallel and randomized clinical evaluation of in-office dental bleaching with violet LED (405-410 nm). Photodiagnosis Photodyn Ther 2022; 38: 102739.
7) Zanin F. Recent advances in dental bleaching with laser and LEDs. Photomed Laser Surg 2016; 34: 135-136.
8) Silva Daltro TW, Gomes de Almeida SA, Dias MF, Lins-Filho PC, da Silva CHV, Guimarães RP. The influence of violet LED light on tooth bleaching protocols: In vitro study of bleaching effectiveness. Photodiagnosis Photodyn Ther 2020; 32: 4-7.
9) Coutinho DS, Silveira L, Nicolau RA, Zanin F, Brugnera A. Comparison of temperature increase in in vitro human tooth pulp by different light sources in the dental whitening process. Lasers Med Sci 2009; 24: 179-185.
10) Castanho GM, Zamboni SC, Torres CRG. Influence of gel color on in vitro syrface and intrapulpal temperature rise dyring blye light-activated tooth bleaching. Gen Dent 2009; 57: 146-150.
11) 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.
12) Loretto SC, Libdy MR, Ribeiro F do S da R, Braga EMF, Carneiro KGK, Silva e Souza Júnior MH. Influence of whitening gel on pulp chamber temperature rise by in-office bleaching technique. Rev Odontol da UNESP 2013; 42: 432-438.
13) Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965; 19: 515-530.
14) Mondelli RFL, Soares AF, Gabriel E, Pangrazio K, Wang L, Ishikiriama K, *et al*. Evaluation of temperature increase during in-office bleaching. J Appl Oral Sci 2016; 24: 136-141.
15) Andreatta LML, Soares AF, Bombonatti JFS, Furuse AY, Mondelli RFL. Whitening gel and light source influence on pulp chamber temperature. RSBO Rev Sul-Brasileira Odontol 2015; 12: 185-190.
16) Carrasco TG, Carrasco-Guerisoli LD, Fröner IC. In vitro study of the pulp chamber temperature rise during light-activated bleaching. J Appl Oral Sci 2008; 16: 355-359.
17) Martín J, Ovies N, Cisternas P, Fernández E, Oliveira Junior OB, De Andrade MF, *et al*. Can an LED-laser hybrid light help to decrease hydrogen peroxide concentration while maintaining effectiveness in teeth bleaching? Laser Phys 2015; 25: 1-5.
18) Martín J, Vildósola P, Bersezio C, Herrera A, Bortolatto J, Saad JRC, *et al*. Effectiveness of 6% hydrogen peroxide concentration for tooth bleaching —A double-blind, randomized clinical trial. J Dent 2015; 43: 965-972.
19) Cavalli V, Kury M, Melo PBG, Carneiro RVTSM, Florez FLE. Current status and future perspectives of in-office tooth bleaching. Front Dent Med 2022; 3: 1-5.
20) Cuppini M, Leitune VCB, De Souza M, Alves AK, Samuel SMW, Collares FM. In vitro evaluation of visible light-activated titanium dioxide photocatalysis for in-office dental bleaching. Dent Mater J 2019; 38: 68-74.
21) Costa JL de SG, Besegato JF, Zaniboni JF, Kuga MC. LED/laser photoactivation enhances the whitening efficacy of low concentration hydrogen peroxide without microstructural enamel changes. Photodiagnosis Photodyn Ther 2021; 36: 102511.
22) Costa JL de SG, Nogueira BR, Junior OBDO, Pretel H. Association of microabrasion and tooth whitening with LED/laser system in the treatment of incisor hypomineralization: 3-year follow-up. Photodiagnosis Photodyn Ther 2021; 33: 2020-2022.
23) Sari T, Celik G, Usumez A. Temperature rise in pulp and gel during laser-activated bleaching: In vitro. Lasers Med Sci 2015; 30: 577-582.
24) 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.
25) Álvarez-Quiceno D, Rojas-Martínez PA, Cruz-González AC. Change of dental color and temperature through two bleaching agents boosted with light emitted by diodes. J Esthet Restor Dent 2021; 33: 1010-1016.
26) Kabbach W, Zezell DM, Pereira TM, Albero FG, Clavijo VRG, De Andrade MF. A thermal investigation of dental bleaching in vitro. Photomed Laser Surg 2008; 26: 489-493.
27) Costa JL de SG, Besegato JF, Zaniboni JF, Vitória MS, Gelio MB, Kuga MC. Whitening efficacy of low concentration hydrogen peroxide photoactivated with blue or violet LED. Photodiagnosis Photodyn Ther 2022; 22: 103028.