

Comparison of temperature increase in in vitro human tooth pulp by different light sources in the dental whitening process

Daniela Soares Coutinho · Landulfo Silveira Jr. ·
Renata Amadei Nicolau · Fátima Zanin ·
Aldo Brugnera Jr.

Received: 29 August 2007 / Accepted: 18 January 2008 / Published online: 15 February 2008
© Springer-Verlag London Limited 2008

Abstract This work evaluated the increase in dental pulp temperature caused by different light sources, used in the dental whitening process, following the irradiation protocol from the light manufacturer. Human incisor, canine and premolar teeth were used. A whitening gel made of hydrogen peroxide 35% v/v and a condenser agent were applied to each tooth, on the vestibular surface, and was activated by five different light sources: photo-polymerizer with blue bandpass filtered halogen lamp (HL) (600 mW, $\lambda=430\text{--}480$ nm), blue light emitting diode (LED) (BL) (1 W, $\lambda=470$ nm), blue LED associated with infrared diode laser (BL+IL) (120 mW, $\lambda=795$ nm), green LED (GL) (600 mW, $\lambda=530$ nm) and green LED associated with infrared diode laser (GL+IL) (120 mW, $\lambda=795$ nm), with the equipment turned on, an exposure time of 1 min, and resting time of 30 s, repeated three times. The temperature was measured at the beginning and ending of exposure by a digital thermometer (type K thermocouple), placed inside the dental pulp chamber. Analyzing the mean temperature variation that occurred along the irradiation time, we found that the BL and BL+IL group presented the highest temperature variations, mainly in the incisor tooth. The GL and GL+IL presented the lowest temperature increase. The maximum temperature

variation reached was 5.5°C for the BL+IL in the incisor tooth. The HL presented a smaller temperature variation than the BL did, but it had a residual temperature when the light was off. The GL and GL+IL promoted a non-significant temperature increase, as low as 1°C, even with total power equal to the that of the HL.

Keywords Dental whitening · Hydrogen peroxide · Pulp · Temperature increase · Thermal changes · Green and blue LED · Infrared laser

Introduction

The number of people searching for brighter teeth has been increasing over the past decade. A recent survey found that 80% of adults aged 18 years to 49 years said that they would like to have whiter, brighter teeth. Over the past 5 years, the demand for tooth bleaching has increased by more than 300%. New materials and equipment are under development to meet that demand, and, currently, there are several whitening techniques available for clinical and home use [1, 2].

The most commonly used technique is home whitening, proposed by Haywood and Heymann in 1989 [3], in which the patient remains for some hours (usually overnight) for 1 or 2 weeks with a resin arch model filled with whitening material. However, this technique is inconvenient, creating gingival irritation, discomfort caused by the model, long time for treatment, bitter flavor of the whitener and possible generation of gastric problems due to swallowing of the whitener, leading to discontinuity of treatment in more sensitive patients [4]. More recently, a whitening process has been presented which is done in the dentist's office

D. S. Coutinho · L. Silveira Jr. (✉) · R. A. Nicolau
Institute of Research and Development (IP&D),
Universidade do Vale do Paraíba (UNIVAP),
Av. Shishima Hifumi, 2911, Urbanova,
12244-000 São José dos Campos, SP, Brazil
e-mail: landulfo@univap.br

F. Zanin · A. Brugnera Jr.
Laser Therapy and Photobiology Center,
Institute of Research and Development (IP&D),
Universidade do Vale do Paraíba (UNIVAP),
São José dos Campos, SP, Brazil

without the use of models, by using whitening materials activated with visible, high-power, light sources [5], bringing rapid treatment and comfort to patients.

To accelerate the whitening process, hydrogen peroxide 35%v/v is used. When it decomposes oxygen free radicals are liberated, which are unstable and very reactive ions, possessing in its structure an unpaired electron. To become stable, this oxygen ion captures an electron from surrounding molecules, such as the pigments present in the enamel surface. This process can result in a break up of the complex chain of pigments, making them clearer [6].

The activation of this chemical agent that is involved in the whitening process can be accelerated by light or heat, which increases the temperature of hydrogen peroxide, speeding up the oxygen ion liberation and, consequently, the whitening effect [5, 7]. The objective of the light source is not directly to whiten the teeth, but to promote activation of the whitening product by absorbing light from the photosensitive agent (a dye) and transferring the absorbed energy to the peroxide [8, 9].

The effectiveness and safety of light-activated whitening systems have received considerable attention from dentists, since there is a great concern in maintaining pulpar vitality during the whitening process, avoiding dangerous dental thermal heating [10], which could lead to tooth sensitivity and, ultimately, pulp damage [11].

For several years photo-polymerization devices made of filtered halogen lamps have been used for the decomposition of hydrogen peroxide in whitening gels. Photopolymerizers with standard halogen lamps emit light in the blue spectral region, by means of bandpass filtering of the emitted light through the incandescence of a tungsten filament. Although high power is achieved in the blue region, the filament lamp produces considerable amounts of heat, worsening the degradation of the blue filter caused by the lamp's infrared emission [12]. Also, the light-induced whitening process needs the tooth to have a longer exposure to the light, so the temperature increase could reach ultimate values and cause pulpar damage.

Goodis et al. [13] and Powell et al. [14], using the halogen lamp for resin curing, found that the increase in pulp temperature was proportional to the tooth's exposure time. Zach and Cohen [15] found that an increase in temperature of 3.3°C resulted in reversible variations in pulpar histology, but when the temperature increase exceeded 5.6°C, approximately 15% of the teeth examined had a loss of pulpar vitality. Baik et al. [16] found that, when excited with filtered halogen lamp and argon laser, the absorption-enhancing colorants applied to the whitening gel could increase the intrapulpal temperature from 5°C to 8°C, which might have a further impact on patient sensitivity and pulp health after this procedure. Other authors consider that the safe temperature threshold for

the root canal when light treatment (infrared diode laser) is applied to teeth is as high as a 7°C increase [17].

Recently, a device was introduced that activates hydrogen peroxide, based on light emitting diode (LED) technology, which, through a luminescence process, produces light in the visible region of the spectrum, with low power dissipation [6, 18]. The light from a LED is produced by energized electron recombination when crossing a P-N semiconductor material junction (a quantum effect) that is properly polarized. The light produced has a narrow bandwidth, which is different from the halogen lamp, which needs the heating of a metallic filament so that it becomes incandescent (by the Joule effect) [12, 19, 20]. Therefore, the LED has an emission spectrum that is narrower than that of the filtered halogen light, through its divergence and non-coherence. Very recently, LED devices were associated with diode lasers emitting in the near-infrared, which, with appropriate energy density, are being used to desensitize the teeth under whitening [16, 21]. Those studies showed that near-infrared laser could improve the inflammatory response of the pulpar tissue, reducing pulp damage and relieving pain after the whitening process.

Suliaman et al. [22], by using different lamps and laser sources, found that lamps did not increase the pulpar temperature of incisor teeth, either with or without the use of gel, but the laser raised the temperature to 86°C without the use of gel and up to 16°C with gel. The gel, by absorbing the light at the tooth surface, could reduce the internal pulpar temperature.

Goodis [13] stated that heat production varies significantly between different models and manufacturers of halogen lamp photo-polymerizers and that, to reduce the pulp thermal heating, one must select an appropriate light source. Then, if the temperature increase depends on the type of light, the temperature elevation effect provoked by the newly launched blue and green LED devices associated or not with the near-infrared laser must be analyzed, verifying which light could reduce this thermal heating and avoiding non-reversible pulp injuries.

Several studies have proposed the use of thermocouples to evaluate tooth temperature directly during light irradiation for whitening purposes [23–26]. Luk et al. [24] applied light for 30 s and compared the temperatures of the outer enamel and inner dentin surfaces before and after irradiation with halogen and infrared light, and argon and CO₂ laser, with a control group. Suliaman et al. [25] used a diode with different powers (from 1 W to 3 W) to activate the bleaching agent at labial surfaces and measured the pulp chamber temperature on the upper and lower central incisors, lateral incisors and canines with a thermocouple. Eldeniz et al. [26] measured the temperature rise in the pulpal chamber of maxillary central incisors with a J-type

Table 1 Types of light sources used with hydrogen peroxide gel for tooth whitening

Type	Output optical power	Wavelength	Tip diameter	Power density
Halogen lamp	600 mW	430–480 nm	1.2 cm	530 mW/cm ²
Blue LED	2 LEDs at 500 mW each	LEDs 470 nm	1.6 cm	500 mW/cm ²
Green LED	2 LEDs at 300 mW each	LEDs 530 nm	1.6 cm	300 mW/cm ²
Blue LED + laser	2 LEDs at 500 mW each Infrared diode laser at 120 mW	LEDs 470 nm Laser 795 nm	1.6 cm 1.4 cm	500 mW/cm ² 20 mW/cm ²
Green LED + laser	2 LEDs at 300 mW each Infrared diode laser at 120 mW	LEDs 530 nm Laser 795 nm	1.6 cm 1.4 cm	300 mW/cm ² 20 mW/cm ²

thermocouple wire that was connected to a data logger. Different light sources, such as halogen light, LED and laser diode, and two different bleaching agents were used.

This work was intended to analyze the temperature increase in the human dental pulp chamber provoked by five different light sources with different wavelength and power configurations, some of them currently used in the dental clinic for the whitening process. Five different light source configurations were selected: (a) a resin photopolymerizer with a filtered halogen lamp; (b) a blue LED device; (c) a blue LED device associated with near-infrared diode laser; (d) a green LED device; and (e) a green LED device associated with near-infrared diode laser, the latter being new to dentistry, with few studies having been done on its temperature effect in whitening procedures.

Material and methods

For the proposed work five different light source configurations were used: (a) a standard photo-polymerizer with filtered tungsten halogen lamp (HL) (model Light 2000, Cleanline Industria e Comercio de Produtos Odontológicos Ltda, Taubaté, SP, Brazil); (b) a blue LED device (BL) and (c) blue LED associated with infrared diode laser (BL+IL) (model Easy Bleach, Cleanline); (d) a green LED device (GL), and (e) a green LED associated with infrared diode laser (GL+IL) (model Easy Green, Cleanline). Light source characteristics, such as power, wavelength and power density, are presented in Table 1.

Nine human teeth were used, divided into three groups: group I (three incisors), group II (three canines), group III (three premolars), extracted due to chronic periodontal disease from patients of a particular clinic in São Paulo, (SP, Brazil). The protocol was approved by the Committee on Ethics in Human Research of the Universidade do Vale do Paraíba. After extraction, the teeth were stored in saline solution 0.9% and frozen to -10°C . Before the experiments, all teeth were hydrated with saline solution to reach room temperature. The teeth were then cleaned with a periodontal curette and finally with a rubber goblet, rock pomes and

water. They were packed with gauze and autoclaved for 30 min at 120°C and kept hydrated for 24 h.

The apical third portion of each tooth root was sectioned with the aid of a double-faced diamond disc under water refrigeration. The pulp chamber and root conduit were widened with a high-speed diamond drill, under water refrigeration. The teeth were irrigated with saline solution from a hypodermic syringe with a needle, and the remnant pulp was removed by aspiration with endodontic cannulas. The remaining radicular and coronary pulp was removed with endodontic rasps.

In order to support the teeth for the whitening process, we used a tooth plug-in support from the Laboratory of Endodontology of the Ribeirão Preto School of Dentistry, University of São Paulo, as seen in Fig. 1. The prepared teeth were plugged to the support in acrylic slots and were fixed with red dental wax. A type K thermocouple (IEC584 rule, temperature range -200°C to $1,200^{\circ}\text{C}$) was introduced into the pulp chamber, and the entrance hole was also closed with red dental wax. The thermocouple was plugged into a digital thermometer (model TD801, ICEL, Manaus, AM, Brazil), which provided a temperature range from 0°C to 100°C , with a resolution of 0.1°C .

After placing the tooth in the support and adjusting the thermocouple inside the root, we measured the initial temperature after a 3 min stand by. A whitening gel (model Whitenss HP kit, with hydrogen peroxide 35% v/v and red condenser, FGM, Joinville, SC, Brazil) was prepared in the proportion of three drops of hydrogen peroxide to one of red condenser, this used to make a gel with consistency for ease of application and color to absorb the visible light.

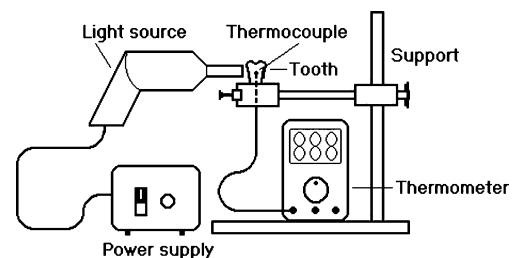


Fig. 1 Apparatus for measuring tooth temperature with the photopolymerizer, blue and green LED light sources

Table 2 Mean (*M*) and standard deviation (*SD*) values of the temperature variation for each group of teeth as a function of the light source used for whitening. *n*=24 temperature measurements for each

Tooth type	HL		BL		BL+IL		GL		GL+IL	
	M	SD	M	SD	M	SD	M	SD	M	SD
Incisor	1.46	0.83	2.71	1.83	3.17	2.18	0.33	0.48	0.58	0.50
Canine	1.25	0.72	2.04	1.08	2.29	1.47	0.21	0.66	0.25	0.58
Premolar	1.67	0.93	1.08	0.72	1.83	1.30	0.25	0.44	0.33	0.56

With the aid of a plastic spatula, we placed the gel on the vestibular surface of the tooth, to form a 1 mm layer. This procedure followed the instructions indicated by the manufacturers of the light source and the whitening gel.

The gel was activated by the light source, with a distance of 1 mm from the light tip to the gel surface. This distance was small enough for us to consider the diameter of the light source tip to be the same as the light spot at the irradiated tooth surface. Irradiation time and temperature were measured as follows: first irradiation for 1 min, and the temperature was measured immediately after; one interval of 30 s, with the temperature measured at the end; second irradiation for 1 min, with the temperature measured again; another interval of 30 s with temperature measured; and the last irradiation of 1 min, with the temperature measured at the end, totaling 3 min of light application. Then the tooth was left to rest for 3 min, and the final temperature was verified. This protocol followed the time used in a typical light-induced whitening process, i.e., 1 min exposure and 30 s cooling. The measurements were repeated for each tooth group and each light source: HL, BL, BL+IL, GL, GL+IL. A total of eight temperature measurements were made for each tooth for each device, totaling 120 measurements for each tooth group (three teeth per group, five light sources, eight measurements each tooth). The temperature variation was then calculated (final temperature minus initial temperature). The light power density for each light source is presented in Table 1. The energy density applied can be obtained by multiplying the power density by the time exposure (3 min=180 s).

Mean temperature variation and standard deviation during all irradiation times for each tooth and light source were calculated and plotted using Microsoft Excel '97. The difference among the three teeth types and five light sources was tested by non-parametric analysis of variance (ANOVA) with InStat software (GraphPad Software, San Diego, CA, USA). The null hypothesis (H_0) was considered to be the equality of the temperature increase measured on each tooth for each light source compared to each other. The statistical significance level *P* to reject the null hypothesis was considered to be 0.05 (5% significance level).

tooth and light used. *HL* halogen light, *BL* blue LED, *BL+IL* blue LED and infrared laser, *GL* green LED, *GL+IL* green LED and infrared laser

Results

The mean temperature variation and standard deviation for each type of tooth, depending on the light source used to activate the whitening gel, is shown in Table 2 and plotted in Fig. 2. This plot represents the mean temperature variation that occurred during the whole irradiation time, from the beginning of the light irradiation (room temperature) to the 3 min resting time at the end of irradiation. By analyzing the temperature variation, we found that the BL and BL+IL group presented the highest mean temperature variations. The GL and GL+IL presented the lowest temperature increases.

As seen in Fig. 2, the incisor teeth had a higher temperature increase than the other teeth for all LED light sources, with higher values for the BL and BL+IL. The canines had an intermediate temperature increase, and the premolars had the lowest temperature increase, considering BL and BL+IL. Halogen lamp provoked teeth thermal heating, with small differences among tooth type. Green light produced a small temperature increase.

A non-parametric ANOVA was carried out for each light source compared with the others and the results are shown in Table 3. The statistical significance level *P* was lower than 0.05 (rejecting the null hypothesis) in the incisor, canine and premolar teeth for HL, BL and BL+IL compared with both GL and GL+IL, with an exception for the premolar BL versus GL+IL. The HL and BL had no

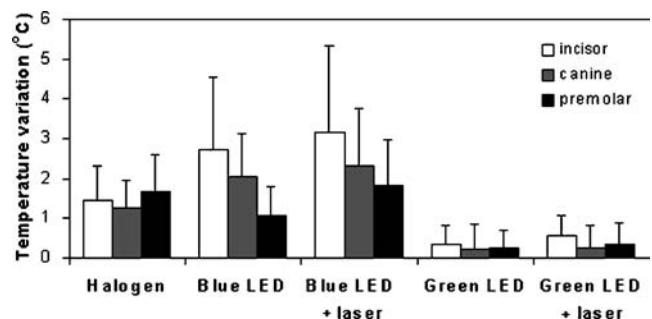


Fig. 2 Plot of the mean and standard deviation of the temperature variation for each group of teeth as a function of the light source used for whitening gel activation

Table 3 Results of the non-parametric ANOVA of intergroups applied to the measured temperatures. *HL*) halogen light, *BL* blue LED, *BL+IL* blue LED and infrared laser, *GL* green LED, *GL+IL* green LED and infrared laser, *ns* not significant, *I* incisor, *C*, canine, *P* premolar

Parameter	HL			BL			BL+IL			GL		
	I	C	P	I	C	P	I	C	P	I	C	P
BL	ns	ns	***									
BL+IL	ns	ns	ns	ns	ns	ns						
GL	***	***	***	***	***	**	***	***	***			
GL+IL	***	***	***	***	**	ns	***	***	**	ns	ns	ns

** and *** indicate 0.01% and 0.001% statistical significance tested by non-parametric ANOVA, respectively.

statistical significance with the BL+IL. The HL source compared with the BL had statistically significant difference only for premolar teeth. GL versus GL+IL had no statistical differences. These statistically significant values are indicated by asterisks in Table 3.

Results of the temperature variation for each type of tooth depending on the light source as a function of irradiation time are plotted in the Fig. 3. For all samples, it was found that there was an increase in the temperature during irradiation and the stabilization or decreasing during the 30 s inter-cycle interval, depending on the light source. For the BL and BL+IL, when the light was turned on, the temperature increased, and, with the light off, the temperature showed a little decrease. For the GL and GL+IL, the temperature rise was not very intense (less than 1°C), but the temperature also decreased after the light had been turned off. For the HL, the temperature variation was less than that with the BL and BL+IL, but the temperature stayed constant while the lamp was turned off. The HL had a higher temperature at the end of the resting time than the other sources had. The maximum temperature variation reached was 5.5°C for the BL+IL in the incisor teeth at the end of the irradiation sequence.

Discussion

To preserve the pulpar vitality during the light-activated whitening procedure, it is important to take into account a

possible thermal effect on the pulp of healthy teeth. Zach and Cohen [15] were the first to observe that a temperature increase higher than 5.5°C would irreversibly damage the pulp tissue. In our work, the BL+IL device presented a high temperature rise observed in all the dental groups using the irradiation procedure adopted by the whitening gel manufacturer, and a temperature rise of approximately 5.5°C was obtained for the incisor teeth (Fig. 3) at the end of the irradiation. According to Goodis et al. [13], the power intensity and wavelength of the light used in the whitening procedure must be taken into consideration, because of the generated heat that can cause irreversible damage to the pulp. The BL and BL+IL laser generated a great amount of heat and tooth temperature. The near-infrared laser itself was responsible for a small increase in the temperature (the statistical difference between BL and BL+IL was not significant), with the main temperature rise being caused by the different absorption coefficient of the red condenser of the whitening gel in the blue and green spectral regions [27] and also by the higher power of the BL than of the other light sources.

The infrared laser has little effect on the temperature increase. Studies have shown that near-infrared laser could improve the inflammatory response of the pulpar tissue, reducing pulp damage and relieving pain after the whitening process [16, 21]. Its use would diminish patients' sensitivity complaints after the procedure.

The BL caused a higher temperature increase than the GL did. Both LED light sources are considered to be cold light, but the BL presented 1 W power (power density=500 mW/cm²),

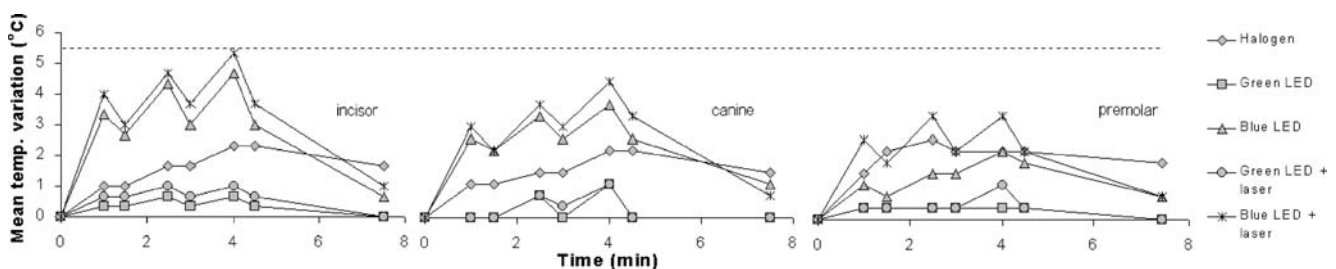


Fig. 3 Temporal evolution of the mean temperature variation measured in the incisor, canine and premolar teeth compared with the type of light source. Three irradiations were performed, of 1 min

each with a time interval of 30 s and a stabilization time of 3 min after the last irradiation. The *dashed line* represents the threshold of temperature rise for pulp damage [15]

in contrast to the 600 mW power (power density=300 mW/cm²) of the GL, this difference alone being responsible for a higher temperature when the BL was used. Moreover, the green light interacts better with the red pigment of the gel than the blue light does. In a study conducted by Coutinho and Silveira Jr. [27], the absorption coefficient of the red condenser was measured using the light emitted from the green and a blue LEDs used in this work. The study showed that the green LED presented an absorption coefficient higher than that of the blue LED (absorption coefficient of 4.2 cm⁻¹ and 2.4 cm⁻¹, respectively), which would increase the temperature only at the enamel surface, not at the deeper layers, explaining part of the lower temperature reached by green light in the pulp chamber, shown in this work.

It was found that the halogen lamp had a cumulative thermal effect, with temperature constant even when the lamp was turned off during the 30 s cooling interval, and a long time to decay when the lamp was definitely turned off during the resting time, as seen in Fig. 3. The residual temperature variation was 1.5°C, even after 3 min with the power off. The effect was more pronounced on the premolars, with a temperature increase higher than that from the other sources (except the BL+IL) and higher than that of the other teeth, and higher final temperature (after the 3 min resting period). This can be explained by the thicker wall that could work as a thermal capacitor. Also, the broadband light from this type of source heats not only the gel, but the whole tooth structure.

The color of the gel influences the final temperature, since different light sources have different emission wavelengths and the absorption peak changes following gel color. This could induce different peroxide reactions and bleaching effects that were not evaluated. The red gel had been chosen because it is the most used in dental clinics, due to the wide absorption spectral band and possibility because of its use with the widespread and cheap halogen lamp. Sulieman et al. [25] found that the presence of the bleaching gel reduced the temperature increases seen within the pulp chamber. Therefore, the gel acts as a selective absorber near the dental surface, preventing light penetration into the internal tooth structure.

Based on the results, we found that the power and the type (wavelength) of the light source influenced the temperature variation. The BL+IL, which presented a higher power than the other sources did, produced a temperature increase as high as 5.5°C. The HL presented a smaller temperature variation than the blue light but had a residual temperature when the light was off. The GL and GL+IL promoted a non-significant temperature increase, as low as 1°C, even with total power equal to the HL.

Professionals performing in-office teeth whitening by using a light source to accelerate the process should consider the specific bleaching agent being used, as well

as the potential risk of the teeth heating and pulp damage. A specific combination of color agent and light that demonstrates good whitening and little temperature rise, combined with desensitizer ability, should be selected.

References

1. Carrasco LD, Guerisoli DM, Rocha MJ, Pécora JD, Froner IC (2007) Efficacy of intracoronal bleaching techniques with different light activation sources. *Int Endod J* 40:204–208
2. Carrasco LD, Guerisoli DM, Pécora JD, Froner IC (2007) Evaluation of dentin permeability after light activated internal dental bleaching. *Dent Traumatol* 23:30–34
3. Haywood VB, Heymann HO (1989) Nightguard vital bleaching. *Quintessence Int* 20:173–176
4. Dostalova T, Jelinkova H, Housova D, Sulc J, Nemeč M, Miyagi M, Brugnera A Jr, Zanin F (2004) Diode laser-activated bleaching. *Braz Dent J* 15:SI3–SI8
5. Sun G (2000) The role of lasers in cosmetic dentistry. *Dent Clin North Am* 44:831–850
6. Torres CRG, Borges AB, Kubo CH, Gonçalves SEP Araújo RM, Celaschi S, Giorgano C, Arcas F (2004) Clareamento Dental com Fontes Híbridas Led/Laser (ed). Taubaté, Evidência Visual, p 140
7. Reyto R (1998) Laser tooth whitening. *Dent Clin North Am* 42:755–762
8. Christensen GJ (2002) The tooth-whitening revolution. *J Am Dent Assoc* 133:1277–1279
9. Zanin F, Brugnera A Jr A (2004). Clareamento dental com luz laser (ed). Santos, São Paulo, p 103
10. Tavares M, Stultz J, Newman M, Smith V, Kent R, Carpino E, Goodson JM (2003) Light augments tooth whitening with peroxide. *J Am Dent Assoc* 134:167–175
11. Kabbach W, Pereira TM, Benetti C, Zzell DM (2006) Análise Térmica Superficial da Raiz e Câmara Pulpar Durante Processo de Clareamento Dental - Estudo In Vitro. http://www.abfm.org.br/rep2006/programa/trabalhos/g_tmarti_69.pdf
12. Kurachi C, Magalhães DV, Eduardo CP, Bagnato VS (1998) Análise Térmica para um Pré-Molar Humano Exposto à Luz Laser. *Rev Fis Apl Instrum* 13:5–8
13. Goodis HE, White JM, Andrews J, Watanabe LG (1989) Measurements of temperature generated by visible-light-cure lamps in an in vitro model. *Dent Mater* 5:230–234
14. Powell GL, Anderson JR, Blankenau RJ (1999) Laser and curing light induced in vitro pulpal temperature changes. *J Clin Laser Med Surg* 17:3–5
15. Zach L, Cohen G (1965) Pulp response to externally applied heat. *Oral Surg* 19:515–530
16. Baik JW, Rueggeberg FA, Liewehr FR (2001) Effect of light-enhanced bleaching on in vitro surface and intrapulpal temperature rise. *J Esthet Restor Dent* 13:370–378
17. Gutknecht N, Franzen R, Meister J, Vanweersch L, Mir M (2005) Temperature evolution on human teeth root surface after diode laser assisted endodontic treatment. *Lasers Med Sci* 20:99–103
18. Wetter NU, Barroso MC, Pelino JE (2004) Dental bleaching efficacy with diode laser and LED irradiation: an in vitro study. *Lasers Surg Med* 35:254–258
19. Mills RW, Jandt KD, Ashworth SH (1999) Dental composite depth of cure with halogen and blue light emitting diode technology. *Br Dent J* 186:388–391
20. Cefaly DFG, Ferrarezi GAO, Tapety CMC, Lauris JRP, Navarro MFL (2005) Microhardness of resin-based materials polymerized with LED and halogen curing units. *Braz Dent J* 16:98–102

21. Calmon WJ, Brugnera A Jr, Munin E, Lobo PDC, Zanin F, Pécora JD, Barbin EL, Espano JCE (2004) Estudo do Aumento de Temperatura Intra-Pulpar Gerado pelo Clareamento Dental. *Rev Gaúcha Odont* 52:19–24
22. Sulieman M, Addy M, Rees JS (2005) Surface and intra-pulpal temperature rises during tooth bleaching: an in vitro study. *Br Dent J* 199:37–40
23. Zhang C, Wang X, Kinoshita JI, Zhao B, Toko T, Kimura Y, Matsumoto K (2007) Effects of KTP irradiation laser irradiation, diode laser, and LED on tooth bleaching: a comparative study. *Photomed Laser Surg* 25:91–95
24. Luk K, Tam L, Hubert M (2004) Effect of light energy on peroxide tooth bleaching. *Am Dent Assoc* 135:194–201
25. Sulieman M, Rees JS, Addy M (2006) Surface and pulp chamber temperature rises during tooth bleaching using a diode laser: a study in vitro. *Br Dent J* 200:631–634
26. Eldeniz AU, Usumez A, Usumez S, Ozturk N (2005) Pulpal temperature rise during light-activated bleaching. *J Biomed Mater Res B Appl Biomater* 72:254–259
27. Coutinho DS, Silveira L Jr (2006) Comparação dos Coeficientes de Absorção da Luz Emitida por um LED Verde e um LED Azul em um Espessante na Cor Vermelha. *Rev Assoc Bras Odontol* 2:12–13