RESEARCH ARTICLE

Temperature Increase during Tooth Whitening

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Abstract
Among various risks associated with the tooth whitening, the present study investigates the temperature increase that might cause irreversible damage on intracanal tissue. A human mandibular central incisor was subjected to this study. Under various operational conditions (including tooth thickness, irradiation time, distance and angle, presence of whitening agent, etc.), it was found that the critical intracanal temperature (above which the intracanal tissue could be subject to the irreversible damage) of 42.5°C can be monitored by an externally measuring the tooth surface temperature, independent of whitening conditions (irradiation source, its angle and duration, distance from the tooth surface) as well as tooth properties (tooth thickness, size, thermal conductivity).

Keywords: Whitening, Enamel, Dentin, Pulp, Exothermic Reaction, Temperature Increase, Critical Intracanal Temperature

Introduction

History and current status
It is known that there are three essential parameters defining beautiful face or facial expressions; i.e., (1) symmetry, (2) golden aspect ratio and (3) averaged face. While expressing emotional feeling that are engendered through straightforward mind such as pleasure, joy, satisfaction, fascination, devotion, respect, hope, horror, surprise, ululation, disappointment, and even religious ceremonial events, people express face and move entire body in symmetrical manner. On the other hand, mental conditions such as irony, unexpected, forced smile, regretful, insult, deception or fraud will be expressed consciously, purposefully or intentionally showing asymmetric facial expression. Without exceptions, such former symmetric facial expression is accompanied with tooth appearance. If radiant smile (which is believed to be contagious in healthy manner among everyone around you) is accompanied with white and bright teeth, a sign of health and affluence should be accordingly recognized. It is also well stated that tooth whitening plays an important role in dentistry not only from the aesthetic reason offering a dental attractiveness with healthy and bright smile and boosting self-esteem, but also normal occlusal function as well as intraoral hygiene concept which the latter might be responsible to systemic diseases such as diabetes as a typical example.

Tooth color is generally considered as a main factor in dental attractiveness, particularly in the anterior region of upper dentition. Discoloration of the teeth may be resulted from intrinsic or extrinsic stains. Intrinsic stains are generated by endogenic chromogens within the enamel and dentin, whereas extrinsic stains are caused by the binding of exogenous chromogens to the enamel surfaces [1]. For removing tooth discolorations, there are several methods exercised such as micro- and macro-abrasion and bleaching. According to various sources regarding the history of tooth whitening (or discoloration) [2, 3], a variety of medicament types of sodium hydrochloride, chlorinated lime, chloride, sodium perborate and hydrogen peroxide has been employed for bleaching colored tooth (due to extrinsic staining and a portion of intrinsic staining).

Currently, there are a variety of whitening methods in terms of presence or absence of dental profession’s supervision, including the in-office whitening, take-home whitening and over-the-counter whitening [4]. With either whitening system, the common factor is to utilize a powerful yet safe whitening gel that is applied to the surface of teeth for lightening the appearance of stains, discoloration, and yellowing on the tooth enamel. The whitening products contain carbamide peroxide or hydrogen peroxide to lighten the color deep in the tooth. In general, the concentration of hydrogen peroxides is varied from 3% ~ 15% used for at-home whitening to 15% ~ 43% employed for the in-office practices. The whitening

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gel component, either hydrogen or carbamide peroxide, can remove extrinsic and intrinsic stains through oxidative mechanisms. Effects of whitener on various properties of restorative materials have been investigated [5-8]; corrosion [6], compressive strength [7], and diametral tensile strength [8]. The whitening effect is largely dependent on amount of hydroxyl radicals which are produced during the oxidative mechanisms, so that it is recognized to pay special attentions on concentration of hydrogen peroxide, heat temperature (depending on light or heat sources) and controlled pH alkalinity [9-12]. A certain type of whitening gel contains the photocatalyst-type titanium dioxide as an effective additive [13-15].

Moreover, Ahrari, et al. [16] investigated the effect of sodium bicarbonate (NaHCO₃). Due to the tooth sensitivity and possible demineralization under low pH value (pH of 5.2 is the critical value for onset of deminerallization) of whitening agents, use of a re-mineralizing agent such as casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) [17-19] has been recommended during the pre-, on- or post-breeching process.

As to heat/light source used for the tooth whitening, historically it started with halogen light, laser or plasma-arc light, and currently LED source is commonly employed [20]. These external sources can be applied to activate to heat up the hydrogen peroxide gel, thus increasing the rate of oxygen decomposition, which promotes whitening effect [21, 22]. Some of these light sources can cause an increase in the intracanal temperature, which can increase the incidence of post-operative sensitivity [23, 24]. Regarding to the light source, the in vitro study showed that the conventional halogen lamp caused the greatest increase in intra-pulpal temperature and the green LED the lowest [25]. There were many reports indicating the intracanal temperature increase with various types of light sources [26-29], the maximum temperature for the intracanal to bear (i.e., intracanal critical temperature increase) should be 5.5°C; accordingly, the intracanal temperature should not exceed the temperature of 42.5°C (=37°C as normal body temperature + 5.5°C), which should be independent of type of external light sources and manner of irradiations.

**Risks of temperature increase during the whitening treatment**

Outcome of tooth whitening depends on various treatment factors [30], including concentration of whitening gel, pH value thereof, externally applied heat for promoting the oxidative reaction of whitening gel, additionally maybe extra heat due to the exothermic heat generated during the oxidative reaction. Besides these essential factors, there should further include frequency of whitening treatment, duration of treatment and the non-bleach composition of the employed product. All these factors should not exhibit any harmful effect if the treatment is conducted under controlled and well-managed procedure under supervisions of dental professions.

In general, if the temperature during chemical reactions is increased by 10°C, the resultant reaction rate will be doubled, depending on the activation energy involved in the reaction (see footnote for details).

Footnote:
To investigate the influence of temperature raises on efficacy of whitening, it is convenient to use the Arrhenius equation compare the reaction rate constants (k) between two temperatures.

Let A be frequency reaction factor, E activation energy for reaction, R gas constant (=8.314 kJ/mol) and T absolute temperature, the reaction rate constant (k) at temperature T can be obtained by the following equation: 

\[k = A \exp(-E/RT)\]

If the reaction temperature increases by 10°C, new reaction rate constant (k') at T+10 can be expressed by 

\[k' = k \exp(-E/(R(T+10))\]

To investigate the effects of the temperature increase, it is simply to compare the both k values. Hence, we have 

\[k'/k = \exp(-E/R(T+10)-1/T)\]

indicating that the ratio depends on both E and T values.

Substituting T (as our initial temperature) of 37°C (normal body temperature, which is 310°K = 273+37) and new \(T' = 320°K (=273+47)\), yielding that 

\[k'/k = \exp(-E/R(1/320-1/310))=\exp[1.008x10^{-4}x(R/E)]=\exp(1.293x10^{-6})\]

Further substituting E of, for example, 50kJ/mol, we have 

\[k'/k=1.83\]

which can be aproximated be 2. Hence, it can be said that by increasing the reaction temperature by 10°C, roughly the reaction rate can be doubled. It should be noted that the above estimation depends on the value for E (reaction activation energy).

Since we are dealing with the chemical reaction that is taking place in human intraoral environment, compatibility of such temperature increase should be taken into serious considerations. The use of light sources in the bleaching process reduces the time required and promotes satisfactory results. However, these light sources can cause an increase in the pulp temperature. Whitening process has been reinforced by development of new technologies allowing patients to get faster and better results [31, 32], Shahabi, et al. [33] investigated different light-activation sources and compare their efficacy of in-office tooth whitening; the light sources included LED-activation, KTP (potassium-titanyl-phosphate) laser activation, diode laser activation, Nd: YAG laser activation, and CO₂ laser activation. Colorimetric evaluation was carried out before and after treatment with a spectrophotodimeter. It was concluded that (i) all bleaching techniques were effective, and (ii) however, the KTP laser-activated bleaching was significantly more efficient, closely followed by the CO₂ laser-activated bleaching technique.

Due to demands from both professions and patients for increasing chemical rate (in other words, shortening the whitening treatment time), powerful light source is currently more often employed. These external light sources exhibit the ability to heat the hydrogen peroxide gel, thus increasing the rate of oxygen decomposition, which promotes bleaching [19, 27].
Accordingly, it must be pointed out that light activated whitening treatments, in general, are accompanied by an increase in temperature on the tooth surface as well as inside the pulp chamber, which may contribute to changes in the health of the pulp, culminating in a simple increase in sensitivity up to extreme situations such as necrosis [34].

Although it is beneficial to apply powerful irradiation source to promote whitening chemical reaction, there should be a concern of additional temperature increase during such reactions. Our preliminary study indicated that the exothermic reaction of hydrogen peroxide under Papillon II (Ken’s Brighten System) was recognized and the temperature difference between with and without whitening gels was 3.1°C (=15.5 – 12.4) which appears to be minimal when compare to heat generated by light source, although should not be ignored.

When the increase in intracanal temperature exceeds 5.5°C, irreversible damage is induced in the pulp tissue. The in vitro pulp chamber temperature increase induced by the light-activated dental bleaching technique (35% hydrogen peroxide) was investigated under different light sources; a light-emitting diode (LED)- laser system, a LED unit and a conventional halogen light [35]. The light sources were positioned perpendicular to the buccal surface at a distance of 5 mm and activated during 30 seconds. It was concluded that (i) when the bleaching agent was not applied, the halogen light induced the highest temperature increase (2.38 +/- 0.66°C), (ii) the LED unit produced the lowest temperature increase (0.29 +/- 0.13°C); but there was no significant difference between LED unit and LED-laser system (0.35 +/- 0.15°C), and (iii) when the bleaching agent was applied, there were significant differences among groups: halogen light induced the highest temperature rise (1.41 +/- 0.64°C), and LED-laser system the lowest (0.33 +/- 0.12°C); however, there was no difference between LED-laser system and LED unit (0.44 +/- 0.11°C) [35]. Andreatta, et al. [36] evaluated the in vitro temperature increasing in the pulp chamber during in-office bleaching with different gel concentrations (35%, 25%, 15% and 10%) and light sources (blue hybrid LED/laser and violet hybrid LED/laser). Results indicated that (i) significant differences between groups were observed; the blue LED without the gel induced the smallest heat (37.5 ± 0.2°C) and the blue LED with 15% gel caused the highest heat (38.2 ± 0.3°C), and (ii) the combination of violet LED with the 10% gel caused no significant increase in temperature compared to the control in which light was used without gel; concluding that no increase in pulp chamber temperature was higher than 2°C [36].

Sulieman, et al. [37] measured the surface and intra-pulpal temperature increases in vitro on upper and lower anterior teeth during tooth whitening procedures under four lamps; a plasma arc lamp, a xenon-halogen lamp, a standard halogen lamp and a diode laser lamp. It was reported that temperature rise ranged from 0.44°C (luma arch) to 86.3°C (laser) with no bleaching gel present, and intra-pulpal temperature increases ranged from 0.30°C to 15.96°C. It was further indicated that (i) the presence of the bleaching gel reduced temperature increases seen at the tooth surface and within the pulp, (ii) the increase in the intracanal temperature with most bleaching lamps was below the critical threshold of a 5.5°C increase, and (iii) the only lamp that produced an intracanal temperature increase above this threshold was the laser-based lamp [37]. Mondelli et al. [25] measured the increase in intracanal temperature induced by different light-activated bleaching procedures (conventional halogen, hybrid light of LED/diode Laser), a high intensity LED, and a green LED light) with and without the use of a bleaching gel (35% hydrogen peroxide). It was reported that (i) the presence of a bleaching gel generated an increase in intracanal temperature in groups activated with halogen light, hybrid light, and high intensity LED, (ii) compared to the other light sources, the conventional halogen lamp applied temperature variations, and (iii) the conventional halogen lamp caused the highest increase in intracanal temperature, and the green LED caused the least; concluding that there was an increase in temperature with all lights tested and the maximum temperature remained below the critical level (5.5°C) [25]. On the other hand, it was reported that external heat applied to the teeth can cause pulp damage in varying degrees, depending on the magnitude and duration of the increase in temperature [28]. Loretta, et al. [38] evaluated the influence of whitening gel on temperature increase in the pulp chamber, using the in-office photoactivated dental bleaching technique. It was concluded that the whitening gels significantly affected the temperature increase (2.8°C ~ 8.3°C) in the pulp cavity during bleaching procedure.

**Objective of the study**

The specific aim of the present research is (1) to measure the possible temperature increase measured at intracanal space by the light sources, (2) to measure simultaneously tooth crown surface temperature under various light sources, and (3) to correlate the tooth crown surface temperature and intracanal temperature.

**Materials and Methods**

**Tooth preparation**

A human mandibular central incisor was subjected to the present study. Although the main target area for whitening is maxillary anterior teeth, why we selected the mandibular central incisor because it exhibits the thinner crown thickness, so that more temperature-sensitive than maxillary anterior teeth. The camber open was conducted from lingual side of a crown to remove intracanal contents. Intraoral x-ray gauge image (taken by No.21-157; YDM Corp., Tokyo Japan) was further digitized to measure the thickness of tooth crown portion (Image J ver. 1.51; National Institutes of Health, Maryland).

The thickness of tooth crown was adjusted to 3.5, 3.0, 2.5 and 2.0mm by cutting the intracanal side wall by the diamond bar (TR-13C; MANI, Inc., Tochigi, Japan) (Figure 1).
In order to measure temperature at the external surface of tooth crown ($T_s$) and temperature at intracanal wall ($T_p$), the coated thermocouples (Type-K TC-K-F-0.1-WP (HAYASHI DENKO Corp., Tokyo, Japan) were adhered to the central portion of each locations with applying the adhesive resin (4META/MMA-TBB adhesive resin; Super Bond, Sun Medical Corp., Moriyama, Japan) (Figure 2a, 2b).

**Whitening method**

As to the agent for the whitening, Opalescence Boost (Ultradent Products Inc., Utah; hereafter is referred as OP) with Concool gel (Weltec CORP., Osaka, Japan, referred as CC) as a control agent was used. The PenCure 2000 Whitening Head (J. MORITA MFG Corp., Kyoto, Japan, referred as PC 2000) was employed as an LED irradiator. OP and CC agents
were applied in such a way to cover the thermocouples on tooth crowns with amount of about 1mm thick and Silicone grease (GS-01; AINEX Corp., Tokyo Japan) which as previously heated at was filled into intracanal open space.

With the above arrangement, irradiating tube of PC 2000 was fixed at about 5.0 mm from the central external surface of the tooth crown and perpendicular to tooth surface. The LED irradiation was conducted continuously under the high output mode (i.e., 2000mW/cm²) until the temperature T_P reaches about 45.0°C. This irradiation was repeated for 5 times for all cases.

**Temperature measurement**

Both T_S and T_P were measured with 5.0 second interval by the LOGGER GL820 (Graphtec Corp., Yokohama, Japan). For every temperature measurement, the starting temperature was controlled at T_P of 37±2°C and the temperature T_S (when T_P reached the critical pulpal temperature of 42.5°C) was measured along with the time from starting to the time when T_P reached the critical pulpal temperature of 42.5°C, respectively. Temperature increase was determined by taking average over 5 readings.

Furthermore, for measuring possible temperature increase due to exothermic reaction of the whitening gel OP, temperature increment of the OP was compared with those of CC as a control.

**Results and Discussion**

**Exothermic reaction**

To find the temperature increase only from the exothermic reaction of whitening gel, the gel was applied on a resin plate and an enamel surface, and the irradiation was applied for 30 min. It was found that (1) on a resin plate, the initial temperature (23.9°C) changed to 36.3°C (+12.4°C) while (2) the temperature increase on then enamel surface was 23.5 °C→ 39.2°C (+15.7°C). It is therefore, suggested that the temperature increase due solely to the oxidative reaction of whitening gel (mainly composed of H₂O₂) was exothermic reaction, causing at least 3.3°C (=15.7 – 12.4). In a reality, there should be more than a single tooth which is subjected to the whitening reaction, resulting in that the temperature increase due to exothermic reaction might be higher than the present data (3.3°C) and these additional temperature increase might affect the final critical intracanal temperature (i.e., 42.5°C).

**Temperature variation at locations on tooth surface**

OP agent was pasted on the entire surface of the enamel. Temperatures at three locations (center of enamel, top edge of the enamel and ED-junction) were measured through the thermocouple (Type-K TC-K-F-0.1-WP) under irradiation with PenCure 2000. Each location was 3mm apart from each other. It was shown that (1) by prolonging the irradiation time, the temperature constantly tends to increase (after about 25 second irradiation), and (2) the center portion of enamel surface (55°C) exhibited the highest temperature, following by edge portion (50°C) and ED-junction (45°C).

**Temperature differences on tooth crown surface and intracanal wall**

Figure 3 depicts the interrelation between tooth crown surface temperature (T_S) and intracanal temperature (T_P) during the tooth whitening treatment with the crown thickness of 3.9mm. It was indicated that (1) at the intracanal wall, the critical temperature (37.0+5.5°C=42.5°C) was reached after 5min and 17sec from onset of irradiation (at 28.7°C) and after about 3min from the body temperature (37.0°C), and (2) the
The temperature difference between crown surface temperature and intracanal temperature was about 15°C and these two localized temperatures are well correlated each other (r ≈ 0.98).

### Affecting parameters

There could be various parameters affecting on the critical intracanal temperature (42.5°C). It was found that, in order to reach the intracanal temperature at 42.5°C, thinner the crown thickness, the lower crown surface temperature for reaching 42.5°C at intracanal space. This can be applied to maxillary anterior tooth, since the TS - TP relationship should be independent of crown thickness. According to reported data on thermal conductivity of human enamel as well as dentin [39-41], it can be said that enamel and dentin were good thermal insulators, so that and the teeth subjected to heat application in the bleaching technique did not suffer any type of visible alteration [39]. However, it was found that not only thickness of the crown but irradiation duration is also affecting on adverse intracanal critical temperature; i.e., the thinner the crown is, the shorter irradiation time for reaching the critical intracanal temperature.

Crown thickness is recognized to vary in a wide range, but it can be narrowed since the normal practice for tooth whitening treatment is limited from central incisor to first premolar; hence the thickness range (enamel + dentin) can be from 2.7 mm (=1.4mm for enamel +1.3mm for dentine) to 1.8mm (0.8mm + 1.0mm, respectively) [41]. If this limitation is applied to Figure 4, it can be suggested that, for monitoring the intracanal critical temperature of 42.5°C, it is recommended to control the crown surface temperature not exceed 52°C and/or the irradiation should not exceed the continuous 12-second operation.

### Main finding toward the safety indicator during tooth whitening

As the chief objective of the present study, it is very important to control the intracanal temperature TP not to exceed at least 42.5°C by monitoring crown surface temperature TS. Within limits of the obtained results, it can be said that, when TS exceeds 50°C, the intracanal temperature TP reaches 42.5°C, independent of crown thickness (see Figure 4).

### Conclusions

In the present study, among various risks associated with the tooth whitening, the adverse temperature increase experienced at the intracanal space has been investigated. Within limited results obtained throughout this study, it is concluded that (1) the critical intracanal temperature of 42.5°C (= 37°C + 5.5°C) can be monitored externally by controlling the tooth crown surface temperature, (2) if the tooth crown surface temperature exceeds 50°C, the intracanal space exhibits critical temperature, and (3) this temperature increase could be accompanied by the exothermic heat during the oxidative reaction of whitening agent.

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### References


