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D Claiborne
G McCombs
M Lemaster
MA Akman
M Laroussi

Low-temperature atmospheric pressure plasma enhanced tooth whitening: the next-generation technology

Authors' affiliations:
D Claiborne, G McCombs, M Lemaster, School of Dental Hygiene, Old Dominion University, Norfolk, VA, USA
MA Akman, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA, USA
M Laroussi, Laser and Plasma Engineering Institute, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA, USA

Correspondence to:
Denise Claiborne
School of Dental Hygiene
Old Dominion University
Norfolk
VA 23529
USA
Tel.: +1 757 6835949
Fax: +1 757 6835239
E-mail: dclaibor@odu.edu

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Abstract: *Objectives:* To evaluate the safety and effectiveness of the plasma pencil (PP) device in conjunction with H_2O_2 gel. The purpose of this study was to determine whether LTAPP delivered using the PP would enhance the tooth-whitening process while causing no thermal threat. *Methods:* The study consisted of thirty extracted human teeth that were randomized into two groups: Group I received LTAPP plus 36% H_2O_2 gel at 10, 15 and 20 min and Group II received 36% H_2O_2 gel only at the same time intervals. Tooth surface temperature was measured periodically throughout the experiment using a non-contact thermometer. Digital photographs were taken pre- and post-treatment and transferred to Adobe Photoshop for comparison, using the CIELAB Color Value System. Only L^* (lightness) values were evaluated in this study. Data were analysed using descriptive statistics and *t*-test at the 0.05 level. *Results:* The results revealed a statistically significant difference in mean CIE L^* values after exposure to LTAPP plus 36% H_2O_2 gel, compared with 36% H_2O_2 only, in the 10- and 20-min groups (P = 0.0003 and 0.0103, respectively). The temperature in both treatment groups remained under 80°F throughout the study, which is below the thermal threat for vital tooth bleaching. *Conclusion:* Utilizing PP device in conjunction with 36% H_2O_2 safely accelerates and enhances the tooth-whitening process.

Key words: atmospheric pressure plasma; dentistry; tooth whitening

Introduction

Tooth whitening is not a new procedure, yet over the past decade the 'whitening generation' has emerged for which aesthetic appearance is of enormous importance. Increased interest in tooth whitening is due in part to heightened media attention and the growing association between a white smile, overall attractiveness and physical health (1). The demand for in-office 'power' bleaching has grown because consumers want whiter teeth in a short amount of time. Moreover, the number of over-the-counter and professional whitening products available has expanded the opportunity for individuals to use multiple products simultaneously. Consequently, the role of the oral health professional is to educate patients on the benefits and risks of tooth-whitening procedures, as well as provide effective treatment options.

Plasmas

The three states of matter, solids, liquids and gases, are ubiquitous on our planet; however, the majority of the visible universe is made up of a fourth state of matter, referred to as plasma (2). Plasmas can be classified energetically into two groups, thermal plasmas and non-thermal plasmas. Non-thermal plasmas can be cool enough to the touch and can be manipulated at relatively low temperatures, whereas thermal plasmas are difficult to control due to their substantially higher temperatures. Non-thermal plasmas, also known as cold plasma, which low-temperature atmospheric pressure plasmas (LTAPP) are a part of, are commonly used in neon signs, fluorescence tubes and plasma televisions; on the other hand, thermal plasmas are often associated with welding or with phenomena in nature such as lightning, stars and the sun.

Plasma science is a relatively new area of research to the dental profession that blends the disciplines of physics, biology, engineering, medicine and dentistry (2–7). Plasmas are a mixture of neutral atoms and molecules, ions and electrons. Plasma chemistry is complex, yet generally plasmas respond to electric and magnetic fields. LTAPP can produce highly reactive free radicals due to electron–neutral collisions (2, 3, 8). At room temperature and in ambient air, plasmas are capable of producing chemically reactive species such as hydroxyl (OH) and oxygen (O), which exhibit strong oxidative properties.

Foundational research suggests that at low doses, LTAPP can kill pathogenic microorganisms without damaging healthy surrounding tissue cells (2, 4, 5, 8). Studies show that bacteria are incapable of surviving in the hostile environment produced by LTAPP and die within a matter of seconds or minutes (2, 4, 5, 8). In response to a growing body of evidence, a number of biomedical and dental applications are being explored. Potential dental applications include the following: inactivation of oral microorganisms associated with periodontal diseases, dental caries and root canal failures; sterilization; blood coagulation; wound disinfection; surface modification; and tooth whitening (2, 9–11).

Significant research has gone into the development of a device that can deliver targeted LTAPP (9–12). The PP, developed by Laroussi and Lu (13), is one such device that is ideally suited for dental applications (Figs 1 and 2). The PP generates a plume of low-temperature, non-equilibrium plasma at atmospheric pressure. Non-equilibrium plasma is where the various constituents (electrons, ions and neutrals) have different energies. The electrons are very energetic (hot), while the ions and neutrals remain at low energy (cold). As the energetic state of the ions and the neutrals dictates the gas temperature, non-equilibrium plasma exhibits low-temperature operating conditions. In addition, in the case of the PP, the stable, focused plume can be directed at small isolated areas and into microscopic crevices (13). The PP employs two electrodes insulated by a dielectric material. The plasma formation ensues as a result of applied voltage in the kilovolts range. The PP is made of a 25-mm diameter hollow dielectric tube with two copper ring electrodes each attached to the surface of a dielectric alumina disc (see device schematic in Fig. 3). The two electrodes are connected to a high-voltage pulse generator capable of producing pulses with amplitudes of up to 10 kV, pulse widths variable from 200 ns to 10 μs, with a frequency or repetition rate of up to 10 kHz (13). The operating gases can be helium, argon, other noble gases or a combination of gas mixture.

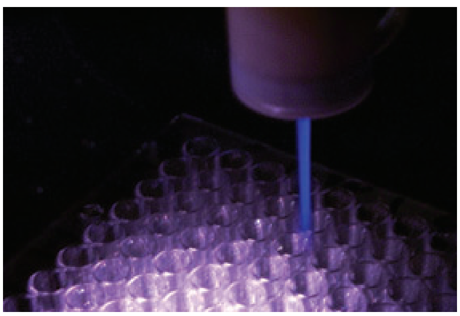

Fig. 1. Plasma pencil in operation.

Fig. 2. Plasma pencil directed at the middle third of tooth.

LTAPP and tooth whitening

Several *in vitro* studies have been conducted using various plasma devices to compare tooth colour changes after exposure to plasma and various liquids and gels (9–12). Methodologies for studies varied, and certain experiments utilized stained

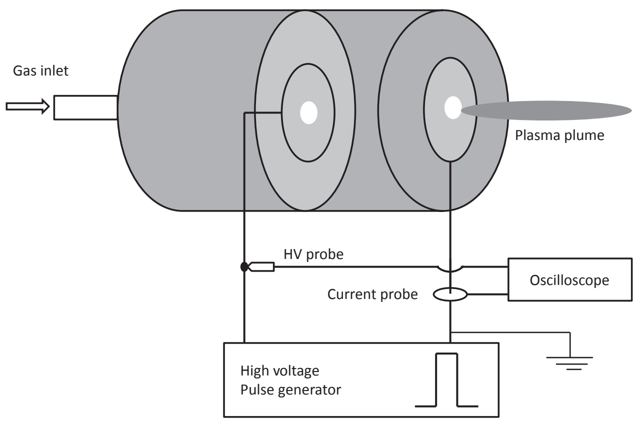

Fig. 3. Schematic of plasma device.

non-vital teeth, while others used natural unstained teeth. Plasma exposure times ranged from 5 to 20 min and H_2O_2 percentages varied from 28 to 35%.

In a study using a helium plasma jet, 28 extracted human teeth were cut longitudinally and randomly assigned to experimental or control groups (9). Internal and external tooth whitening was performed in both groups. The experimental teeth were treated with the plasma jet and 28% H_2O_2, every 30 s, for 10 min. The control group received 28% H_2O_2 only for 10 min. The following variables were measured for both groups: tooth surface temperature via fibre-optic temperature measurement system and tooth surface proteins using the scanning electron microscopy (SEM). Photographs were taken pre- and post-treatment to compare colour changes using the International Commission on Illumination (CIE) classification system. The CIELAB Color Value System measures three dimensions of colour: L^* (lightness–darkness) ranging from 0 (black)–100 (pure white); a* (redness–greenness); and b* (blueness–yellowness). Colour changes were analysed using the Adobe Photoshop software. Results showed an increased brightness of external and internal tooth surfaces in the experimental group, but not in the control group. The experimental group surface temperature increased from room temperature (77°F) and stabilized near (100.4°F) degrees after 1.5 min of operation. Data revealed that combining plasma plus 28% H_2O_2 showed increased lightness compared with H_2O_2 alone. Research suggests that plasma plus H_2O_2 was able to remove surface proteins, which accelerates the whitening process, without thermal damage (9).

In a subsequent experiment, Lee *et al.* evaluated the effect of tooth whitening using H_2O_2 30%, 20 μl every 30 s and a helium plasma jet for 20 min (10). Thirty extracted human teeth were cut longitudinally, one half was randomly assigned to either the experimental or control group. Fifteen half-sections were placed into coffee, and fifteen were immersed in red wine, for 7 days. The experimental group was exposed to plasma and received an application of H_2O_2 every 30 s, for 20 min. The control group was treated with H_2O_2 only for the same amount of time. Digital photographs were taken before and during treatment, at 5-min intervals. To assess colour changes, the CIELAB Color Value System was used. Results showed an overall colour change occurred in the experimental group, whereas no significant colour change occurred in the control group. The difference between brightness and colour tone in the experimental group was significant after 20 min of treatment. The combination of plasma and H_2O_2 improved the bleaching efficacy by a factor of 3.1 for coffee and 3.7 for wine, compared with using H_2O_2 alone (10).

Sun *et al.* (11) evaluated colour, temperature and tooth surface morphology of an air plasma microjet (PMJ), which is an LTAPP plus H_2O_2 gel, compared with H_2O_2 gel alone. Sixty caries-free premolars were divided into three groups: Group A received 35% H_2O_2 gel only and was kept at room temperature for 20 min; Group B received 35% H_2O_2 gel plus PMJ and was kept for 20 min; and Group C received 35% H_2O_2 gel and was placed in an incubator for 20 min. Pre- and post-treatment photographs were taken before and after each plasma exposure. Colour results were analysed with a Crystaleye Spectrophotometer (Olympus Corporation, Tokyo, Japan) in addition; the CIELAB Color Value System was used (11). Results revealed that the PMJ plus H_2O_2 gel group showed greater increase in lightness compared with the two other groups. Throughout the experiment temperatures did not exceed thermal threat limit, and no apparent surface morphology differences were observed in teeth treated with and without PMJ. Researchers concluded the PMJ treatment does not pose safety issues and was effective in accelerating the tooth-whitening process (11).

The effect of atmospheric pressure cold plasma on tooth whitening was evaluated in sixty extracted premolars by Pan *et al.* (12). Experimental teeth were kept whole and divided into three groups: Group A: air blow and saline solution; Group B: PMJ and saline solution; and Group C: 35% hydrogen peroxide gel alone. Each group received a 20-min treatment time. The following characteristics were evaluated: colour, microhardness (enamel hardness) and reactive oxygen species (ROS). Lightness was evaluated pre- and post-treatment using the CIELAB Color Value System. Enamel surface morphological changes were observed using SEM. Reactive oxygen species generated at the plasma–liquid interface are believed to be essential for the tooth-whitening processes; therefore, the presence of three ROS (hydroxyl radical, superoxide anion radical and singlet oxygen) was assessed using electron spin resonance (ESR) spectroscopy. Results revealed the lightness of the teeth in the PMJ plus saline group improved significantly after treatment. Researchers postulated that the improved whitening efficacy of the PMJ with the saline solution is attributed to the ROS from plasma and water interacting with stain molecules on the tooth surface, thus breaking the bonds of the long carbon chains. Researchers concluded that PMJ has no adverse effect on enamel hardness and the use of the PMJ plus saline significantly enhanced the tooth-whitening process (12).

Fundamental research suggests that LTAPP is effective and safe for vital tooth whitening. The purpose of this study was to build on the existing body of evidence and to evaluate whether the PP would safely and effectively enhance tooth whitening, in terms of lightness and temperature.

Methods and materials

Plasma parameters

The PP device used in this experiment generated a plume of low-temperature, non-equilibrium plasma at atmospheric pressure. A steady, focused plume was directed at the facial aspect of the experimental teeth. The following parameters were set: 5 kHz frequency, 500 nanoseconds (ns) pulse width, 7 kV amplitude resulting in unipolar voltage pulses, helium gas with 99.99% purity and a gas flow rate of 1.2 standard litres per minute (slpm).

Laboratory experiment

Thirty extracted, caries-free human teeth (6 anterior and 18 posterior) were divided into two groups: Group I: plasma plus 36% H_2O_2 gel (n = 12) and Group II: 36% H_2O_2 gel only (n = 12). Prior to study initiation, extrinsic stain, calculus and debris were removed using an ultrasonic scaler. Treatment teeth were subdivided according to plasma exposure time (10, 15 and 20 min). The 36% H_2O_2 only group received gel for all three time intervals. The plasma plus 36% H_2O_2 group received gel followed by plasma exposure, for the same time intervals.

Experimental teeth were stabilized in dispensing cups with dental plaster. To localize the target area and gel placement, paper discs were placed over the crown of each tooth; hence, only the facial aspects were exposed. The H_2O_2 gel was approximately 1 mm thick on each tooth. The distance between the nozzle of the PP and the tooth remained at approximately 2.5 cm for the duration of exposure. The gas flow rate was 1.2 slpm. To standardize the lightness measurements, three points were chosen, in a horizontal pattern, across the middle section of the tooth (Fig. 4). Colour was assessed using the CIELAB Color Value System. Only lightness (L^*) was measured using CIE values ranging from 0 (black) to 100 (pure white). Digital photographs were taken pre- and post-exposure using the Canon EOS macro lens with ring flash and 140 magnification digital camera (Cannon USA, Inc., Lake Success, NY, USA). To ensure standardization, photographs were taken using the same camera, photographer, room and lighting. Photographs were transferred to Adobe Photoshop CS5 series for evaluation. Three standardized points were calculated on each photographic image, and the mean L^* values were averaged. The mean L^* values were entered into MICROSOFT EXCEL and analysed. Hypotheses were tested at the 0.05 level of significance.

Tooth surface temperature was measured periodically throughout the experiment using a non-contact thermometer (Extech Instruments, South Burlington, VT, USA). Researchers monitored the temperature to ensure that it remained below the critical value of 106.7°F for vital tooth whitening.

Results

Data indicated a statistically significant difference in lightness using the PP plus H_2O_2 at 10 and 20 min; however, at 15 min, there was no significant difference. The 10-min group revealed a significant difference in mean L^* values after using the PP plus H_2O_2 gel versus H_2O_2 gel only (P-value = 0.0003) (Table 1). Mean difference between pre- and post-photographs for the PP plus H_2O_2 group was 8.48, whereas for the H_2O_2 only group was 1.85 (Fig. 5, Table 2). Data from the 20-min group demonstrated a statistically significant difference in mean L* values using PP plus H_2O_2 gel versus H_2O_2 gel alone (P-value of 0.0103) (Table 3). The PP plus H_2O_2 gel group showed a significant difference between pre- and post-photographs of 8.68, whereas the H_2O_2 only group reported a mean difference of 3.68 (Fig. 6, Table 4). The 15-min group showed no statistically significant difference in lightness between plasma plus H_2O_2 gel versus H_2O_2 gel only (P-value of 0.3815) (Table 5). The PP plus H_2O_2 gel group revealed mean difference between pre- and post-photographs of 4.25, whereas the H_2O_2 only group reported a difference of 3.75 (Fig. 7, Table 6).

External tooth surface temperature was observed periodically through the experiment. Data revealed that tooth surface temperature remained below thermal threat for all groups, thus safe for vital tooth bleaching.

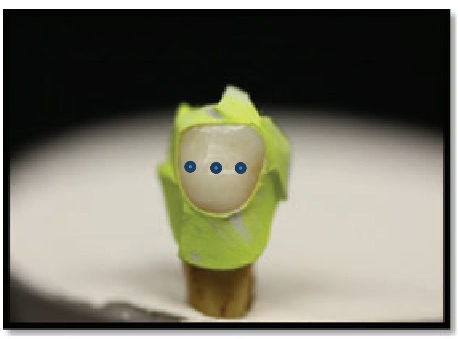

Fig. 4. Target area with three standardized measurement points.

Table 1. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 10 min**

	H_2O_2 gel only	Plasma + H_2O_2 gel
Mean	1.85	8.475
Variance	1.203333333	3.115833333
Observations	4	4
Pooled variance	2.159583333	
Hypothesized mean difference	0	
d.f.	6	
t stat	−6.375524175	
P (T <= t) one-tail	0.0003499*	
t critical one-tail	1.943180274	
P (T <= t) two-tail	0.0006998	
t critical two-tail	2.446911846	

*Statistically significant differences.

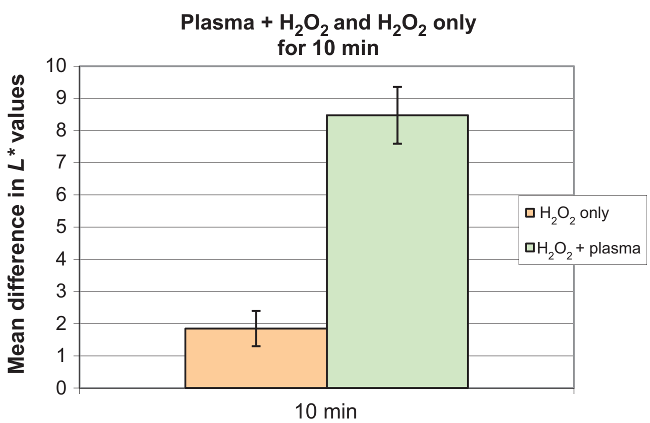

Fig. 5. Mean difference in L^* values between Plasma + H_2O_2 and H_2O_2 only for 10 min.

Table 2. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 10 min**

PP + H_2O_2 gel				H_2O_2 gel only			
Teeth	Pre	Post	Difference	Teeth	Pre	Post	Difference
P	52	60.3	8.3	P	55.6	58.3	2.7
P	67.3	78.3	11	P	59.3	62	2.7
P	58	65	7	P	63.6	64	0.4
A	57	64.6	7.6	A	54	55.6	1.6
Mean	58.575	67.05	8.475*	Mean	58.125	59.975	1.85*
SE	3.1907092	3.8979696	0.8825862	SE	2.1359522	1.8763329	0.5484828
SD	6.3814183	7.7959391	1.7651723	SD	4.2719043	3.7526657	1.0969655

$n = 4$.
P, posterior teeth; A, anterior teeth; PP, plasma pencil.

Table 3. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 20 min**

	H_2O_2 gel only	Plasma + H_2O_2 gel
Mean	3.675	8.675
Variance	3.469167	6.8225
Observations	4	4
Pooled variance	5.145833	
Hypothesized mean difference	0	
d.f.	6	
t stat	−3.11715	
P (T <= t) one-tail	0.01033*	
t critical one-tail	1.94318	
P (T <= t) two-tail	0.02066	
t critical two-tail	2.446912	

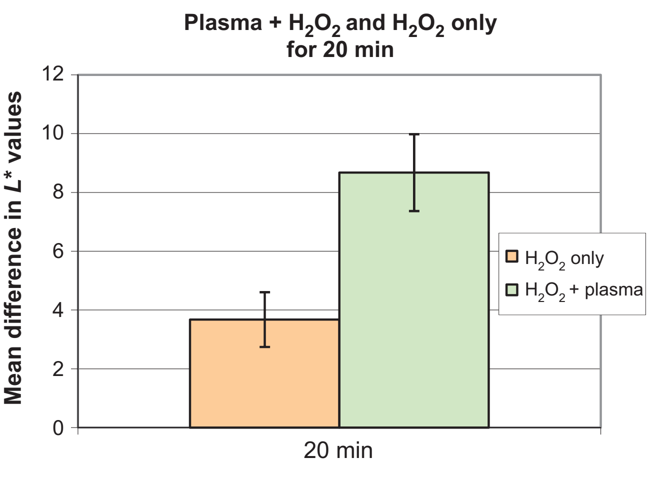

Fig. 6. Mean difference in L^* values between plasma + H_2O_2 and H_2O_2 only for 20 min.

Discussion

The present study explored the effectiveness and safety of LTAPP as a potential method to enhance tooth whitening. The primary purpose of this study was to evaluate the difference in tooth surface lightness utilizing the PP plus 36% H_2O_2, as opposed to H_2O_2 only. Additionally, the experiment analysed external tooth surface temperature to confirm that LTAPP was safe for vital bleaching. Temperatures remained below 80°F for all groups and posed no threat of thermal injury. Prior literature suggest that non-thermal plasma causes no thermal harm and that tooth surface temperatures stabilized between 98.6°F and 104°F (9–11). In addition, the literature indicates that temperatures between 114.8°F and 123.8°F are safe for bleaching non-vital teeth and that temperatures above 106.7°F may lead to irreversible pulpal damage (14, 15).

The following confounding variables may have influenced the overall results in terms of lightness: combining anterior and posterior teeth, differences in baseline colour and surface morphology, as well as the age and dehydration of the experimental teeth. It is suggested that the thickness of the whitening gel may inhibit penetration of the plasma to the target; therefore, other sources of whitening agents or solutions should be considered for future testing. Furthermore, in a study conducted by Lee *et al.*, it was proposed that individual teeth may respond differently to the same bleaching treatments, thus results may vary (9). Theoretically, in the human's oral cavity, no two teeth are identical; each tooth has a unique colour, cusps and groves. For example, the canine tooth has the longest root and the enamel is darker in colour when compared with the rest of the dentition. Therefore, the individual tooth anatomy has also to be taken into consideration when conducting studies addressing whitening methodologies.

Results from the present study revealed significant differences in mean L^* values in the 10- and 20-min PP plus H_2O_2 groups; nevertheless, the 15-min group revealed no statistically significant difference. Baseline lightness values in the 15-min LTAPP group were higher (64.9) compared with the 10- and 20-min LATPP groups (58.6 and 56.3, respectively); therefore, higher baseline lightness values may account for smaller differences between pre- and post-values. Another noteworthy point to consider is in all post-treatment groups for the PP plus 36% H_2O_2 group, the L^* values ranged from 60.3 to 78.3. With regard to the lightness scale, which ranges from 0 (black) to 100 (pure white), it has not been determined whether a human tooth could ever reach pure white. In addition, the overall shade of enamel varies with each person and dentition.

Table 4. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 20 min**

PP + H_2O_2 gel				H_2O_2 gel only			
Teeth	Pre	Post	Difference	Teeth	Pre	Post	Difference
P	60.6	68.6	8	P	63.6	66.3	2.7
P	53.6	65.6	12	P	54.6	60.3	5.7
P	56.3	62	5.7	P	63.3	68	4.7
A	55	64	9	A	65	66.6	1.6
Mean	56.375	65.05	8.675*	Mean	61.625	65.3	3.675*
SE	1.5123795	1.393736	1.3059958	SE	2.3707857	1.7073371	0.931285
SD	3.0247589	2.787472	2.6119916	SD	4.7415715	3.4146742	1.8625699

$n = 4$.
P, posterior teeth; A, anterior teeth; PP, plasma pencil.

Table 5. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 15 min**

	H_2O_2 gel only	Plasma + H_2O_2 gel
Mean	3.75	4.25
Variance	8.843333	0.756667
Observations	4	4
Hypothesized mean difference	0	
d.f.	4	
t stat	−0.32275	
P (T <= t) one-tail	0.381526	
t critical one-tail	2.131847	
P (T <= t) two-tail	0.763052	
t critical two-tail	2.776445	

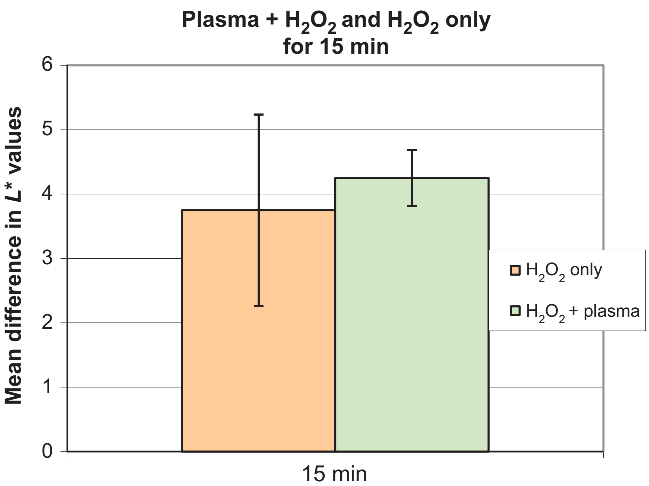

Fig. 7. Mean difference in L^* values between plasma + H_2O_2 and H_2O_2 only for 15 min.

It is postulated that there could be an initial surge in whitening which levels off and then reach peak lightness at the end of the experiment time. In the current study, lightness differences were noted as early as 10 min, whereas in other studies, a significant difference in lightness was not evident until the 20-min interval was reached (9–12). Results from the present study suggest that the use of the PP plus 36% H_2O_2 safely enhanced and accelerated the tooth-whitening process in non-vital teeth; however, results cannot be generalized to vital teeth.

Summary and conclusions

The present study examined the effects of LTAPP on tooth whitening using the PP. Results demonstrate that there was a statistically significant difference in mean L^* values using the PP plus 36% H_2O_2 gel, in the 10- and 20-min groups, yet the 15-min group revealed no statistically significant difference. Several factors were put forth that could have influenced the outcomes such as variations in baseline tooth colour, general characteristics of posterior versus anterior tooth morphology, differences in enamel thickness and the viscosity of the whitening gel. Therefore, future studies should take these variables into consideration.

Although this investigation still is exploratory, the favourable results from this experiment demonstrate that LTAPP-enhanced tooth whitening is plausible. The PP used in this experiment proved to be safe and effective in improving tooth colour, while keeping tooth surface temperatures below the thermal threat. Considering all prior related research with the addition of this study's findings, it is hypothesized that the plasma-whitening effect is conceivable. LTAPP has the potential to either replace traditional whitening agents or serve as a safe, effective augmentation to tooth-whitening procedure.

Clinical relevance

Scientific rationale for study

The rationale for this study was to measure time, lightness, and temperature using slightly different methodologies from previous studies.

Principal findings

In prior studies, it was concluded that LTAPP plus H_2O_2 gel enhances the tooth-whitening process as opposed to using

Table 6. **Mean difference in CIE L^* values between plasma + H_2O_2 and H_2O_2 only for 15 min**

PP + H_2O_2 gel				H_2O_2 gel only			
Teeth	Pre	Post	Difference	Teeth	Pre	Post	Difference
P	68	72.6	4.6	P	53	55	2
P	64.6	69	4.4	P	65.3	69.6	4.3
P	66.6	71.6	5	P	52.6	60.3	7.7
A	60.3	63.3	3	A	50.3	51.3	1
Mean	64.875	69.125	4.25	Mean	55.3	59.05	3.75
SE	1.6769889	2.0846163	0.4349329	SE	3.3860006	3.9720901	1.4868871
SD	3.3539777	4.1692325	0.8698659	SD	6.7720012	7.9441803	2.9737743

$n = 4$.
P, posterior teeth; A, anterior teeth; PP, plasma pencil.

H_2O_2 gel alone. Moreover, increased lightness was seen within 10 min in this study, and tooth surface temperatures remained around 80°F.

Practical implications

The use of LTAPP in conjunction with H_2O_2 gel could potentially reduce the time spent in an in-office whitening procedure by providing a safe enhancement to the tooth-whitening process.

References

1 Heyde M, Wilkins K, Li Y. Current trends in tooth whitening. *Dimens Dent Hyg* 2011; **38**: 41–42.

2 Kong M, Laroussi M. *About Plasmas*. Coalition for Plasma Science, 2003. Available at: http://www.plasmacoalition.org/plasma_writeups/destroying-biohazards.pdf. (accessed 05 August 2011).

3 Laroussi M. Low temperature plasmas for medicine? *IEEE Trans Plasma Sci* 2009; **37**: 714–725.

4 Laroussi M. Low temperature plasma-based sterilization: overview and state-of-the-art. *Plasma Process Polym* 2005; **2**: 391–400.

5 Stoffels E, Fikweert J, Stoffels W, Kroesen W. Plasma needle: a non-destructive atmospheric plasma source for fine surface treatment of biomaterials. *Plasma Sources Sci Technol* 2002; **11**: 383–388.

6 McCombs GB, Darby ML. New discoveries and directions for medical, dental and dental hygiene research: low temperature atmospheric pressure plasma. *Int J Dent Hyg* 2010; **8**: 10–15.

7 Lemaster MF, McCombs GB. The future looks bright. *Dimens Dent Hyg* 2011; **9**: 40–43.

8 Laroussi M. Nonthermal decontamination of biological media by atmospheric-pressure plasmas: Review, analysis, and prospects. *IEEE Trans Plasma Sci* 2002; **30**: 1409–1415.

9 Lee HW, Kim GJ, Kim JM, Park JK, Lee JK, Kim GC. Tooth bleaching with nonthermal atmospheric pressure plasma. *J Endod* 2009; **35**: 587–591.

10 Lee H, Mohamed A, Kim G, Lee J. Atmospheric pressure plasma jet composed of three electrodes: application to tooth bleaching. *Plasma Process Polym* 2010; **7**: 274–280.

11 Sun P, Pan J, Tian Y, et al. Tooth whitening with hydrogen peroxide assisted by a direct current cold atmospheric pressure air plasma microjet. *IEEE Trans Plasma Sci* 2010; **38**: 1892–1895.

12 Pan J, Sun P, Tian Y, et al. A novel method of tooth whitening using cold plasma microjet driven by direct current in atmospheric-pressure air. *IEEE Trans Plasma Sci* 2010; **38**: 3143–3151.

13 Laroussi M, Lu X. Room temperature atmospheric pressure plasma plume for biomedical applications. *Appl Phys Lett* 2005; **87**: 113902.

14 Luk K, Tam L, Hubert M. Effect of light energy on peroxide tooth bleaching. *J Am Dent Assoc* 2004; **35**: 194–201.

15 Bushalla W, Attin T. External bleaching therapy with activation by heat, light or laser. A systematic review. *Dent Mater* 2007; **23**: 586–596.