

## Feasibility of nonthermal atmospheric pressure plasma for intracoronal bleaching

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### Abstract

**Park JK, Nam SH, Kwon HC, Mohamed AAH, Lee JK, Kim GC.** Feasibility of nonthermal atmospheric pressure plasma for intracoronal bleaching. *International Endodontic Journal*.

**Aim** To investigate the effect of nonthermal atmospheric pressure plasma on intracoronal tooth bleaching in blood stained human teeth.

**Methodology** Forty extracted single-root and blood stained human teeth were used. The teeth were randomly divided into two groups ( $n = 20$ ): group 1 received 30% HP activated by nonthermal atmospheric pressure plasma in the pulp chamber for 30 min, whilst group 2 received 30% HP alone in the pulp chamber for 30 min. The overall colour changes ( $\Delta E$ ) were assessed using the Commission Internationale de L'Eclairage (CIE) Lab Colour System. The data were analysed using

Student's *t*-test to determine the significant differences.

**Results** The temperature of all teeth was maintained at approximately 37 °C during plasma bleaching. The plasma treatment with 30% HP resulted in significantly higher bleaching efficacy compared to 30% HP alone in discoloured teeth ( $P < 0.05$ ). The average  $\Delta E$  values of group 1 and group 2 were 9.24 (0.37) and 4.47 (1.62), respectively, at 30 min.

**Conclusions** The application of nonthermal atmospheric pressure plasma to intracoronal bleaching could be a novel and efficient therapy in the bleaching of haemorrhagically stained teeth.

**Keywords:** blood stained human teeth, hydrogen peroxide, intracoronal bleaching, nonthermal atmospheric pressure plasma.

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### Introduction

Aesthetics of teeth, including colour, are of great importance to patients. Recently, there has been increasing interest in tooth bleaching because white teeth are being retained longer (Greenwell 2001). Tooth discolouration results from various and multifaceted causes that are classified into extrinsic and

intrinsic discolouration (Watts & Addy 2001). Extrinsic discolouration is caused by the deposition of external chromogens such as food, beverages, and tobacco on the tooth surface. Intrinsic discolouration occurs when the chromogens are deposited within the bulk of the tooth, usually the dentine, and caused by systemic or pulpal factors (Addy & Moran 1995). The main intrinsic factors are pulp haemorrhage, decomposition of pulp, bacteria and their products, tetracycline, pulp necrosis, intracanal medicaments, some endodontic filling materials, and metallic restorations (Plotino *et al.* 2008).

Intracoronal bleaching (internal, non-vital bleaching) has been an accepted clinical procedure in dentistry for over 100 years (Kirk 1893, Spasser

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1961). This technique was modified by Nutting & Poe (1963), who replaced water with 30% hydrogen peroxide (HP). Subsequently, Stewart (1965) described the thermocatalytic method, in which a cotton pellet saturated with HP was placed in the pulp chamber and heated with an instrument. HP is highly effective at removing chromogens deposited on enamel and dentine of teeth (Berger *et al.* 2008). Oxidation-reduction reaction of HP converts darkly pigmented organic molecules into simpler and brighter molecules (Goldstein & Garber 1995). For this therapy, a high concentration of HP (30–35%) is placed into the pulp chamber and activated either by light or by heat, thereby consequently accelerating the bleaching effect (Yazici *et al.* 2007). However, the temperature of the pulp chamber could increase up to 50–60 °C during this process. If a light or heating source cannot be used or is unavailable, achieving the desired bleaching can be a lengthy process. Thus, more safe and efficient methods for intracoronal bleaching therapy are required.

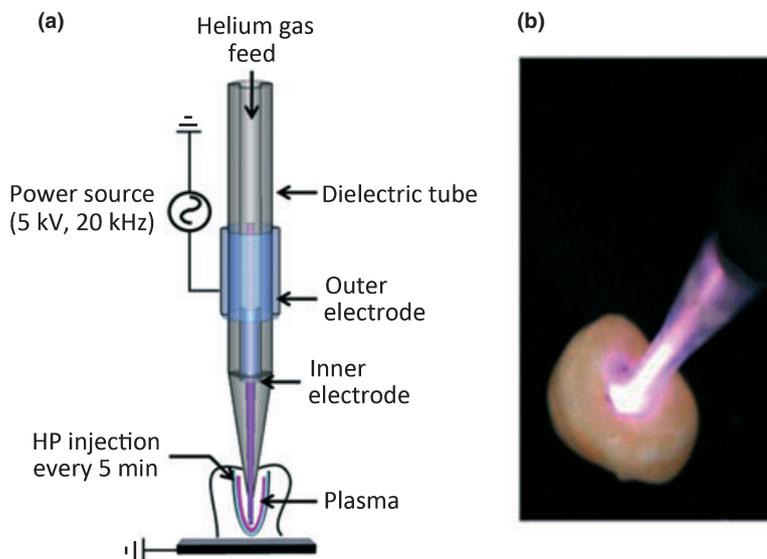
It was previously reported that an effective tooth bleaching method using nonthermal atmospheric pressure plasma instead of a light source (Lee *et al.* 2009). Plasma is the fourth state of matter; it consists of charged particles, radicals, and a strong electric field, so that it is a highly reactive material. Since a plasma jet device generates plasma in the surrounding air at low temperature, it is suitable for direct treatment of target teeth (Xiong *et al.* 2009). Furthermore, the produced energetic ions, free electrons, and

hydroxyl radicals ( $\cdot\text{OH}$ ) from the plasma contribute significantly to tooth bleaching; thus, plasma might shorten the bleaching period because of its synergic effects on tooth bleaching (Iza *et al.* 2008). Therefore, the aim of the present study was to investigate the effect of nonthermal atmospheric pressure plasma on intracoronal tooth bleaching in blood stained human teeth.

## Materials and methods

### Plasma device

The interaction between the nonthermal plasma and a tooth in this experiment is presented in Fig. 1a,b. The nonthermal atmospheric pressure plasma jet device consists of a Teflon tube ( $\epsilon_r = 2.6$ ) that has an inner and an outer aluminium electrode. The outer electrode is connected to a 20 kHz sinusoidal high voltage source with a 5 kV peak voltage. The inner electrode is suspended and not connected to any external power source. It consists of an aluminium cylinder perforated by capillary holes of 1 mm in diameter. Helium gas with a flow rate of 2 L min<sup>-1</sup> is used as feeding gas through the Teflon tube at atmospheric pressure in air. The plasma generation occurs inside the Teflon tube near the powered outer electrode. Subsequently, the plasma is driven out by helium flow to generate a plasma jet outside the Teflon tube in atmospheric pressure air. The jet length increases with the flow rate or applied voltages, and it can reach 3 cm in air.



**Figure 1** The process of intracoronal bleaching using nonthermal atmospheric pressure plasma in the pulp chamber. (a) Schematic diagram of the plasma device and (b) photograph of the process.

### Measurement of tooth temperature

The pulp chamber temperature during bleaching was measured using a fibre optic temperature measurement system (FTI-10 fibre optic signal conditioner, FOT-L-SD fibre optic temperature sensor; FISO Technologies Inc., Quebec, Canada). The distance between the emitting tip of the plasma source (end of the Teflon tube) and the fibre optic temperature sensor was set at 1 cm during 'plasma-on' for 30 min and thereafter set at 'plasma-off' for 20 min. The collected data were presented in graphic form that were monitored in real time and transferred to a computer for recording and display. The results represent three independent experiments.

### Tooth selection and preparation

Forty extracted single-root human teeth were used. All teeth were stored in 0.4% sodium azide solution at 4 °C to inhibit microbial growth. Before experimental use, the teeth were thoroughly scaled with an ultrasonic scaler to remove calculus and remnants of periodontal ligament. The teeth with signs of fracture, caries lesions, or structural anomalies were discarded.

### Tooth bleaching experiments

Standard endodontic access cavities were created with a diamond-coated bur (BR-31 MANI Inc., Tochigi, Japan) with a high-speed handpiece. After the roots were sectioned, the crowns were immersed in 17% ethylene diamine tetraacetic acid (EDTA) for 5 min to remove the smear layer and then rinsed thoroughly with distilled water to remove any traces of the EDTA solution. They were artificially stained by human blood with a modification of the method proposed by Freccia & Peters (1982). Haemoglobin-rich haemolysed blood was collected, and teeth samples were immersed in individual well plates containing 1.5 mL of blood for 4 days. Haemolysed blood was exchanged daily. The samples were then washed in distilled water, dried with absorbent paper, and stored at 37 °C and 100% air humidity in an incubator for 15 days. A cervical filling material of glass-ionomer cement (GC Fuji II LC; GC Corporation, Tokyo, Japan) was placed 1 mm above and 1 mm below the level of the cement-enamel junction. The teeth were randomly assigned to two groups ( $n = 20$ ): group 1 samples were treated with 30% HP (20  $\mu$ L every 5 min) with the plasma jet (applied voltage: half the peak-to-peak amplitude = 5 kV) in the pulp chamber for 30 min, and

group 2 samples were treated with 30% HP (20  $\mu$ L every 5 min) alone in the pulp chamber for 30 min. The cavities were rinsed with distilled water every 10 min and then dried with absorption paper. All samples were photographed at 10 min after treatment.

### Analysis of bleaching efficacy (Lab Colour System)

Teeth were photographed before treatment and at 10 min intervals during the 30 min treatment. The images of teeth were captured with 10  $\times$  magnification digital imaging system consisting of a stereomicroscope (SZ-CTV; Olympus, Tokyo, Japan) connected to a camera (Pixel link PL-B686CU, Canada). The images were stored in a personal computer with the Image-Pro Plus 5.1 software (Media Cybernetics Inc., Washington, DC, USA). The overall colour changes ( $\Delta E$ ) were assessed on the basis of the Commission Internationale de L'Eclairage (CIE, 1979) Lab Colour System (Villalta *et al.* 2006). The  $L^*$  value represents the degree of lightness within a sample and ranges from 0 (black) to 100 (white). The  $a^*$  value represents the degree of greenness (negative  $a^*$ ) or redness (positive  $a^*$ ), whilst the  $b^*$  value represents the degree of blueness (negative  $b^*$ ) or yellowness (positive  $b^*$ ) of the sample. The differences in the values of  $L^*$ ,  $a^*$ , and  $b^*$  in each group were measured using Adobe Photoshop CS2 (Adobe Systems, San Jose, CA, USA), and  $\Delta E$  was calculated for each tooth by using the CIELAB equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

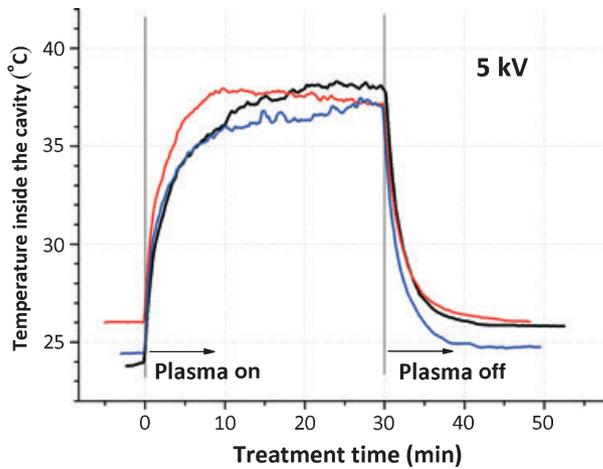
### Statistical analysis

Statistical analysis was performed using SPSS (Version 14, SPSS, Chicago, IL, USA). The difference in  $\Delta E$  values between two groups was determined using Student's *t*-test. Differences with *P* values <0.05 were considered statistically significant.

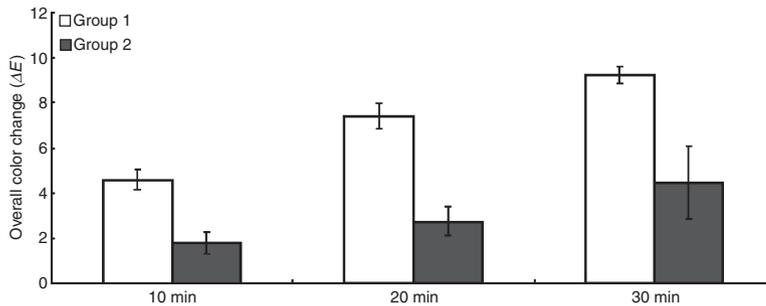
## Results

### Temperature measurement in the pulp chamber

The temperature of the pulp chamber increased from room temperature (25 °C) and stabilized near 37 °C (5 kV voltage) after plasma treatment (Fig. 2). It took approximately 10 min to reach temperatures near 37 °C when the plasma jet was turned on and return to initial room temperature in cases of plasma-on and -off, respectively.



**Figure 2** Measurement of the pulp chamber temperature. The cavity temperature increased after the plasma jet was turned on and then it stabilized near 37.5 °C (5 kV voltage) in three independent experiments.



**Figure 3** The treatment effect of plasma on intracoronary bleaching. The  $\Delta E$  of groups 1 and 2 was measured after plasma treatment for 30 min.

### Tooth bleaching efficacy

Figure 3 represented high efficacy for the plasma jet and HP bleaching compared with HP bleaching alone in discoloured teeth stained by blood. The average  $\Delta E$  values of group 1 were 4.59 (0.42), 7.41 (0.56), and 9.24 (0.37), whilst those of group 2 were 1.81 (0.48), 2.74 (0.65), and 4.47 (1.62) after 10, 20, and 30 min of treatment, respectively (Fig. 3). The mean  $\Delta E$  values of group 1 were approximately 2.07-fold larger than that of group 2 at the end of 30 min. The significance of differences between group 1 and group 2 was analysed by Student's *t*-test. Table 1 shows the mean  $\Delta E$  values after 10, 20, and 30 min of bleaching. There was a significant difference in the bleaching efficacy ( $P < 0.05$ ) between group 1 and group 2.

### Discussion

The most common factors of intrinsic discolouration is pulpal haemorrhagic products following trauma (Rotstein 1998). Traumatic tooth injuries may rupture

blood vessels, leading to blood extravasation in the pulp chamber. This may allow erythrocytes to enter the dentinal tubules, undergo haemolysis, and release haemoglobin. The decomposed haemoglobin releases iron that combines with hydrogen sulphide to produce iron sulphide ( $\text{Fe}_2\text{S}_3$ ), which is responsible for tooth discolouration (Freccia & Peters 1982). For intracoronary bleaching, the combination treatment of HP and light has been accepted for many years as the best technique (Boksman *et al.* 1983, Marin *et al.* 1997). However, thermocatalytic bleaching techniques have problems, such as heat causing intrapulpal temperature increases that may result in internal root resorption (Holmstrup *et al.* 1988, Madison & Walton 1990, Trope 1997, Heithersay 1999, Baik *et al.* 2001).

For biomedical application of light sources, a low temperature device is required because most human tissues can be damaged by even weak thermal stimulation. In this study, plasma treatment did not increase the temperatures of the pulp chamber above body temperature during the bleaching treatment. The plasma jet was in a highly non-equilibrium state that

**Table 1** Data represent mean (SD) of overall  $\Delta E$  in group 1 and group 2

Treatment time (min)	Mean $\Delta E$ (SD)		P-values
	Group 1	Group 2	
10	4.59 (0.42)	1.81 (0.48)	0.000*
20	7.41 (0.56)	2.74 (0.65)	0.000*
30	9.24 (0.37)	4.47 (1.62)	0.007*

\* $\Delta E$  values show significant differences ( $P < 0.05$ ) between the two groups.

allows formation of abundant ions and free radicals whilst maintaining nonthermal characteristics (Lee et al. 2010). The nonthermal plasma was previously shown to have a strong bleaching effect on dentine and stained teeth (Lee et al. 2009, 2010). Furthermore, the combination of plasma treatment with 30% HP enhanced the intracoronal bleaching effect in human blood stained teeth. Considering that plasma increases the production of  $\cdot\text{OH}$ , which is crucial in tooth bleaching, significantly over that produced by HP alone (Lee et al. 2009), the increased amount of  $\cdot\text{OH}$  is thought to play important roles in this intracoronal bleaching (Marin et al. 1997, Goldstein & Meyerstein 1999, Timpawat et al. 2005). The average ( $n = 20$ )  $\Delta E$  value after treatment for 30 min was 9.24 in group 1 and 4.47 in group 2. The bleaching efficacy in group 1 was approximately 2.07-fold better than that in group 2. This result suggests that plasma treatment could bleach teeth within a very short time and lighten the burden imposed on patients. Therefore, the nonthermal atmospheric pressure plasma jet has potential use in the intracoronal bleaching of discoloured teeth.

## Conclusion

Intracoronal tooth bleaching using nonthermal atmospheric pressure plasma associated with 30% HP was more effective than treatment with 30% HP alone. The efficacy of intracoronal bleaching increased over 30 min of treatment in a time-dependent manner, whilst the temperature within the tooth was maintained around 37 °C. The combination treatment of nonthermal atmospheric pressure plasma and HP may be a promising method for intracoronal bleaching.

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