**World Journal of Environmental Biosciences**

Available Online at: **www.environmentaljournals.org**

**Volume 9, Supplementary: 143-147**

**ISSN 2277- 8047**

# Ex vivo investigation of the thermal and structural effects of plasma needle on teeth

**Seyed Hamed Pour Rahmati Khalejan[1], Vedat Keskin[2], Mehrdad Fojlaley[3]***

*[1] Department of Physics, Ondokuz Mayıs University, 55140, Samsun, Turkey.*
*[2]Civil Aviation College, Samsun University, 55420, Samsun, Turkey.*
*[3] Postdoctoral fellow, faculty of engineering, Ardahan University, Ardahan, Turkey.*

**ABSTRACT**

*Atmospheric pressure non-thermal glow discharges have shown a considerable promise for medical and dental applications. These kinds of plasmas are capable of producing short-lived chemical active species, which are propelled toward a surface to be treated. A plasma needle as a source of non-thermal glow discharge, which works under atmospheric pressure, was designed and operated at 20 kHz. The preliminary studies revealed that the device can operate with various flow of different gases such as He and Ar. According to the optical measurements, the reactive species such as O, H, N, and $N_2$ were detected experimentally via emission spectrometer. The plasma temperature was recorded at T = 28°C. The thermal and structural effects of plasma needle on a tooth in ex-vivo conditions were investigated and a safe distance for the plasma-tooth interaction was determined.*

**Keywords:** *Atmospheric-pressure, glow discharges, chemical active species, plasma needle, plasma-tooth interaction*

**Corresponding author**: Mehrdad Fojlaley
**e-mail** ✉ Mehrdad.fojlali @ gmail.com
**Received:** 09 September 2020
**Accepted:** 11 December 2020

## 1. INTRODUCTION

Plasma research has expanded quickly in different fields like ecological, health, material, agronomy, and biomedical investigations (Heinlin *et al.*, 2011; Heinlin *et al.*, 2010). Depending on the temperature of ions, neutrons, and electrons, plasmas can be arranged in classes as "thermal" or "non-thermal". In the case of thermal plasma, the ions, neutrals, and electrons are at the same temperature whereas in cold plasmas electrons are much hotter than the heavy particles (Singh *et al.*, 2014). Since plasma in atmospheric pressure is 40 °C or less, it is considered cold. In recent years, the use of Cold Atmospheric Plasma (CAP) in various biomedical applications, such as sterilization of medical instruments, blood coagulation, and tissue treatment, has received much attention (Fridman *et al.*, 2008; Hoffmann *et al.*, 2013). Scientists have been keen on discovering utilizes for CAP in dentistry (Hoffmann *et al.*, 2013). CAP can be produced by radio frequency, microwave frequency, high voltage AC or DC, etc. (Jiang *et al.*, 2014). The main factors in the interaction of CAP with living tissue and sterilization of instruments are ultraviolet radiation (at a lower rate), charged particles, and active species (Pan *et al.*, 2013). Plasma needle is one of the cold atmospheric radiation which can be designed, manufactured, and studied for medical applications. This system is a single electrode and generally works with He gas (Stoffels *et al.*, 2002). Some experiments have shown that plasma needles can disinfect bacteria, limit cell evacuation without leading to damages neighboring cells, and cancer-cell extirpation (Kuo *et al.*, 2006; Tang *et al.*, 2008; Plewa *et al.*, 2014; Stoffels *et al.*, 2006) and some similar applications in dentistry. In this context, Lee *et al.* showed CAP, instead of light sources, whitened teeth by increasing protein and also helped remove stains from coffee or wine (Lee *et al.*, 2009). Sladek *et al.* used a plasma needle to observe the interactions between plasma and dental tissues. They concluded that plasma treatment is a novel tissue-saving technique, which allows the cleaning of irregular and narrow channels (Sladek *et al.*, 2004). Kong *et al.* studied the effects of CAP brush treatment on dental composite restoration (Kong *et al.*, 2009). Rupf *et al.* applied CAP jets against tooth decay which cause infection and tooth loss (Rupf *et al.*, 2010).

In this study, a new model of plasma needle was designed and constructed. The effects of plasma needle are investigated on a tooth in ex-vivo condition. The production of OH radicals by plasma completely destroys the surface.

## 2. EXPERIMENTAL PROCEDURE

The plasma needle system designed in this work was operated at 20 kHz and produced cold plasma with 1-3 eV. Using an infrared camera, the plasma temperature was obtained around $T$ = 29°C. It can operate under various flow of different gases such as He and Ar. Fig. 1 shows the plasma needle and its components. The operation of the plasma needle under Argon and Helium gases are shown in Fig. 2.

**Figure 1**. Components of plasma needle (left) and plasma needle (right).

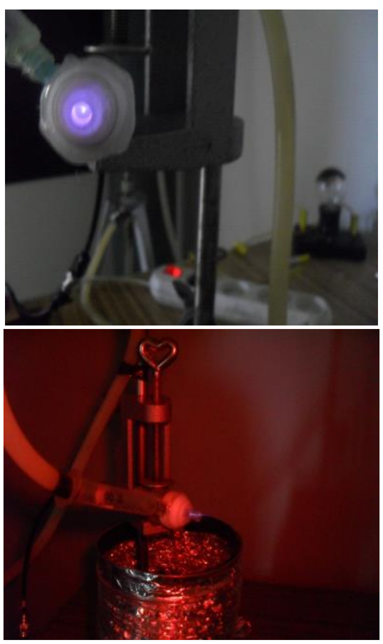

**Figure 2**. The plasma needle works with Argon (left) and helium (right) gases.

To investigate the temperature effects of plasma needles on a tooth, a gap with a distance across 1 mm and depth of 4 mm was made indirectly from the tooth crown towards the tooth enamel so that the end of the cavity was in the cement enamel junction area (Fig. 3).

**Figure 3**. The hole created on the tooth.

A nickel-chrome thermocouple sensor PT100 was placed inside the tooth cavity. The tooth was put at several spaces from the tip of the needle and plasma was applied to it for different periods (Fig. 4).

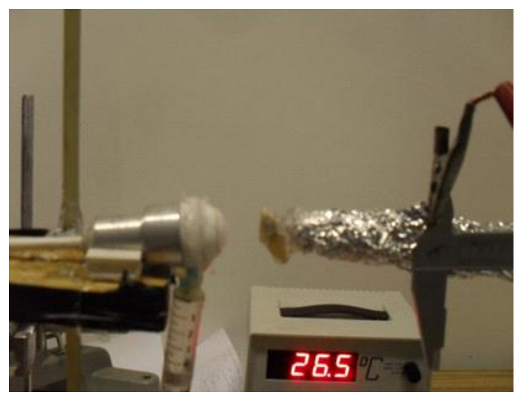


**Figure 4.** Temperature test on the tooth.

## 3. RESULTS AND DISCUSSION

### 3.1 Optical absorption spectrum

The optical emission spectroscopy spectrum was taken for the argon plasma generated on the tip of the needle (Fig 5). According to the optical measurements, in the spectrum, most of the peaks are shown for argon. The reactive species such as H, O, N, and $N_2$ were detected experimentally via an optical emission spectrometer.

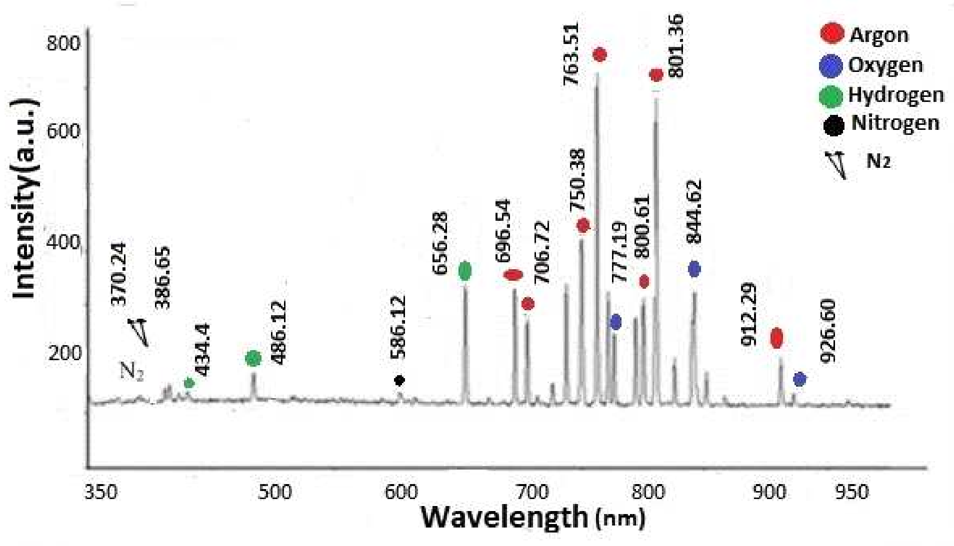


**Figure 5.** Optical absorption spectrum of argon plasma.

**3.2 Effects of plasma on the temperature difference between the tooth and the environment**

Fig. 6 shows the temperature difference of the tooth and the environment relative to the distance for irradiation period times of 30, 60, 90, and 120 s.

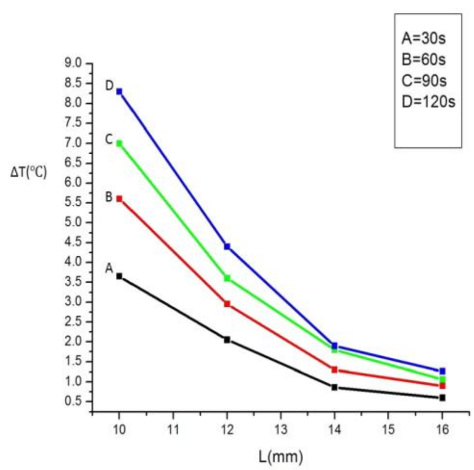


**Figure 6.** Increase in the temperature difference by the distance for different irradiation times.

It was observed that at all radiation times with increasing distance, the temperature difference decreased. Temperature increase by more than 2.3 degrees caused necrosis of the tooth marrow. From the above diagram, optimal distance can be determined for the interaction of plasma with the tooth. For example, for a period of 120 s, the optimal distance is measured as 14 mm. Fig. 7 shows the temperature difference over time at a place of 14 mm from the tip.

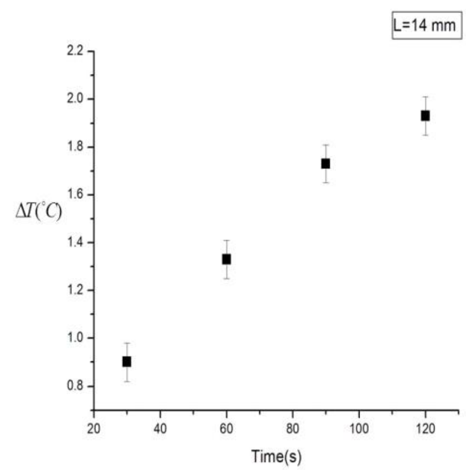


**Figure 7.** Temperature difference diagram in terms of time at a place of 14 mm from tip.

**3.3 Effects of the plasma needle on the tooth**

It can be predicted that plasma radiation can detoxify the tooth and damage the enamel. Therefore, to investigate the effect of needle plasma on the tooth before irradiation, we took a photo of the tooth under a microscope with a magnification of 100. The tooth was irradiated at a distance of 14 mm from the needle for 4 minutes. To study the effect of plasma, again we took photos from the tooth. Fig. 8 shows the image of the tooth before and after CAP treatment.

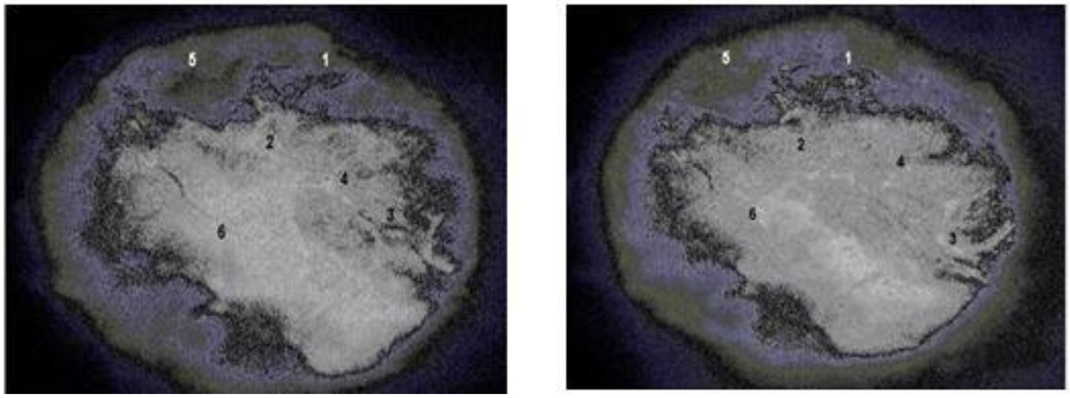


**Figure 8.** Microscopic images of the tooth before (left) and after (right) plasma application.

The position of the fundamental differences (Fig. 8) is indicated by numbers. After irradiation, in positions 1 and 2, the size of the corresponding black contour decreased; in number 3 a black line in position of 4 and 5 black spot, and finally, in the position of 6 narrow lines disappeared.

To show the destructive effects of excessive radiation, we took a tooth photo after the thermometer experiment. The total irradiation time, in this case, was 24 min. The tooth was irradiated at a distance of 14 mm from plasma. Fig. 9 shows the image of the tooth before and after 24 minutes of plasma application.

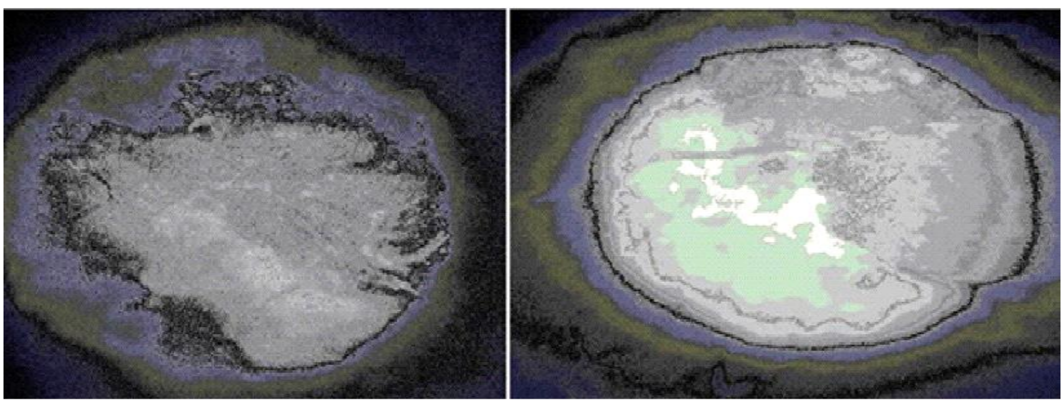

**Figure 9.** Image of the tooth before (left) and after (right) 24 min of plasma application.

From Fig. 9, it can be seen that the tooth configuration has changed completely after 24 min of irradiation.

## 4. CONCLUSIONS

The plasma needle device was developed to study the effects of temperature and its effect on teeth. The temperature effects of the plasma needle on a tooth in the ex-vivo condition were examined. It was shown that the safe range to prevent heat damage can be defined as 14 mm. Also, the effects of plasma on enamel were studied and it was shown that plasma needles can be a good candidate for bacterial decontamination in teeth, and optimal irradiation time for this application should be determined.

## REFERENCES

1. Fridman, G., Friedman, G., Gutsol, A., Shekhter, A. B., Vasilets, V. N., & Fridman, A. (2008). Applied plasma medicine. *Plasma processes and polymers*, *5*(6), 503-533.
2. Heinlin, J., Isbary, G., Stolz, W., Morfill, G., Landthaler, M., Shimizu, T., ... & Karrer, S. (2011). Plasma applications in medicine with a special focus on dermatology. *Journal of the European Academy of Dermatology and Venereology*, *25*(1), 1-11.
3. Heinlin, J., Morfill, G., Landthaler, M., Stolz, W., Isbary, G., Zimmermann, J. L., ... & Karrer, S. (2010). Plasma medicine: possible applications in dermatology. *JDDG: Journal der Deutschen Dermatologischen Gesellschaft*, *8*(12), 968-976.
4. Hoffmann, C., Berganza, C., & Zhang, J. (2013). Cold Atmospheric Plasma: methods of production and application in dentistry and oncology. *Medical gas research*, *3*(1), 21.
5. Jiang, B., Zheng, J., Qiu, S., Wu, M., Zhang, Q., Yan, Z., & Xue, Q. (2014). Review on electrical discharge plasma technology for wastewater remediation. *Chemical Engineering Journal*, *236*, 348-368.
6. Kong, M. G., Kroesen, G., Morfill, G., Nosenko, T., Shimizu, T., Van Dijk, J., & Zimmermann, J. L. (2009). Plasma medicine: an introductory review. *new Journal of Physics*, *11*(11), 115012.

7. Kuo, S. P., Bivolaru, D., Williams, S., & Carter, C. D. (2006). A microwave-augmented plasma torch module. *Plasma Sources Science and Technology*, *15*(2), 266.
8. Lee, H. W., Kim, G. J., Kim, J. M., Park, J. K., Lee, J. K., & Kim, G. C. (2009). Tooth bleaching with nonthermal atmospheric pressure plasma. *Journal of endodontics*, *35*(4), 587-591.
9. Pan, J., Sun, K., Liang, Y., Sun, P., Yang, X., Wang, J., ... & Becker, K. H. (2013). Cold plasma therapy of a tooth root canal infected with Enterococcus faecalis biofilms in vitro. *Journal of endodontics*, *39*(1), 105-110.
10. Plewa, J. M., Yousfi, M., Frongia, C., Eichwald, O., Ducommun, B., Merbahi, N., & Lobjois, V. (2014). Low-temperature plasma-induced antiproliferative effects on multi-cellular tumor spheroids. *New Journal of Physics*, *16*(4), 043027.
11. Rupf, S., Lehmann, A., Hannig, M., Schäfer, B., Schubert, A., Feldmann, U., & Schindler, A. (2010). Killing of adherent oral microbes by a non-thermal atmospheric plasma jet. *Journal of medical microbiology*, *59*(2), 206-212.
12. Singh, S., Chandra, R., Tripathi, S., Rahman, H., Tripathi, P., Jain, A., & Gupta, P. (2014). The bright future of dentistry with cold plasma—review. *J Dent Med Sci*, *13*, 6-13.
13. Sladek, R. E., Stoffels, E., Walraven, R., Tielbeek, P. J., & Koolhoven, R. A. (2004). Plasma treatment of dental cavities: a feasibility study. Plasma science. 32:187.
14. Stoffels, E., Flikweert, A. J., Stoffels, W. W., & Kroesen, G. M. W. (2002). Plasma needle: a non-destructive atmospheric plasma source for fine surface treatment of (bio) materials. *Plasma Sources Science and Technology*, *11*(4), 383.
15. Stoffels, E., Kieft, I. E., Sladek, R. E. J., Van den Bedem, L. J. M., Van der Laan, E. P., & Steinbuch, M. (2006). Plasma needle for in vivo medical treatment: recent developments and perspectives. *Plasma Sources Science and Technology*, *15*(4), S169.
16. Tang, Y. Z., Lu, X. P., Laroussi, M., & Dobbs, F. C. (2008). Sublethal and killing effects of atmospheric-pressure, nonthermal plasma on eukaryotic microalgae in aqueous media. *Plasma Processes and Polymers*, *5*(6), 552-558.