Fluoride application of cold atmospheric plasma on deciduous tooth enamel

Y.M. Kim[1], Y.S. Song[1], S.E. Yun[2], K.H. Park[2], J.H. Bae[1] and G.C. Kim[1,2]

[1] *Research and Development Center, FEAGLE Corporation, Yangsan, South Korea*
[2] *Department of Oral Anatomy and Cell Biology, School of Dentistry, Pusan National University, South Korea*

Abstract: In dentistry, fluoride has been widely used on a tooth surface to prevent dental caries. However, the efficiency of fluoride applications is unclear since the amount of fluoride left on the tooth and for how long it lasts thereon after the treatment has not be determined. However, plasma treatment enhanced the application effect of fluoride and significantly prolonged the maintenance of fluoride on the tooth surface compared to the condition untreated with plasma.

Keywords: cold atmospheric plasma, fluoride application, prevention of dental caries

1. Introduction

Dental caries is a major oral disease, in which the acid produced by bacteria induces mineral loss in teeth. In particular, caries of the primary tooth can progress quickly because it has a more porous structure and more carbonate than permanent teeth.

The progress of the initial caries can be suppressed by remineralizing tooth surface. Fluoride enhances remnineralization of the tooth enamel, prevents dental caries by antibacterial function and resists against erosion. Fluoride forms calcium fluoride on the tooth surface, which increases the hardness of the tooth and its acid resistance by improving the grid structure of the enamel. After fluoride application, however, a large amount of calcium fluoride is washed out of the mouth within a short period. Therefore, fluoridation needs to be re-applied at one week intervals. In addition, repeated ingestion of fluoride can cause fluorosis in children who swallow the gel during the procedure. Although professional fluoride application is known to prevent the progression of caries, there are few effective fluoride products and methods for the mineralization of initial caries lesion. Therefore, new techniques are needed to enhance the coating effect of fluoride and maintain it for long periods.

Plasma, which is considered the fourth state of matter, is a highly active state that contains many radicals, energetic ions, free electrons, strong electric fields, and charged particles. Furthermore, biomedical applications, such as blood coagulation, bacteria sterilization, wound healing, and tooth bleaching have been actively studied because plasma is non-thermal and non-toxic. The strong energy of plasma was hypothesized to separate fluoride from fluoride compounds, allowing fluoride to replace the hydroxyl group of hydroxyapatite in the enamel [1]. In this study, we examined the coating effect of fluoride and its retentivity on deciduous tooth enamel using cold atmospheric plasma.

2. Experimental setup

The extracted or exfoliated human deciduous teeth without caries history were used. enamel specimens were cut to 2 mm x 5 mm x 1mm pieces using a water-cooled diamond saw and stored in distilled water. The specimens were divided into the control group and experiment group.

The low frequency plasma jet is a dielectric barrier discharge (DBD) based design, where a quartz tube is used as the dielectric layer. Voltages between 10kV and 12kV are applies using s sinusoidal power supply at frequencies of around 10 kHz. Helium gas is blown through the inner powered electrode at flow rates between the 2 and 5 slm(standard liters per minutes) range. The plasma plume generated by this device has lengths between 5 and 10 mm, which depends on the applied voltage (Fig. 1).

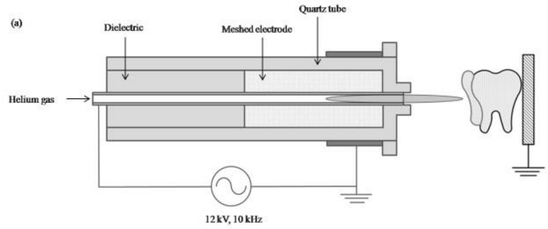

Fig. 1. Schematic diagrams of the plasma device.

The 1.23% APF gel was used. In the control group, the 1.23% APF gel was applied to the enamel surface of a specimen to a 2 mm thickness using a cotton bud. In the experiment group, the middle of the enamel specimen treated with the APF gel was exposed to the plasma jet. The treatment time was 3 min. The treatment was applied four times (group C or E-times) at one week intervals and the specimens were immersed in artificial saliva for one week, two week, three weeks, and four weeks at each treatment respectively (group C or E-times-week).

The fluoride on the enamel surface of the deciduous teeth was detected to measure the fluoride application effect by EPMA. EPMA was performed at an accelerating voltage of 15 keV, a beam current 20 nA, a beam size 10 μm, and a peak time 10 sec. The fluoride was measured in weight percent (wt.%).

3. Results and Discussion

The amount of fluorine increased with increasing number of fluoride treatments in the control group and experiment group. Furthermore, more fluorine was detected in the experimental group (group E-1=5.34, E-2=11.78, E-3=14.02 and E-4=17.1) than the control group (group C-1=2.92, C-2=7.15, C-3=11.29 and C-4=13.29). When the treatment was performed 2 or more times , the experiment group was significantly more effective than the control group ($p < 0.05$). In terms of the maintenance effect, more fluorine was detected in the experiment group than the control group. When the treatment was done 4 times, fluorine was until 2 weeks in group C (group C-4-1 = 9.96 and 4-2 = 3.24), but was detected until 4 weeks in group E (group E-4-1 = 11.81, 4-2 = 8.08, 4-3 = 5.91 and 4-4 = 2.66). Moreover, group E was significantly more effective after 2 weeks than group C ($p < 0.05$) (Fig. 2).

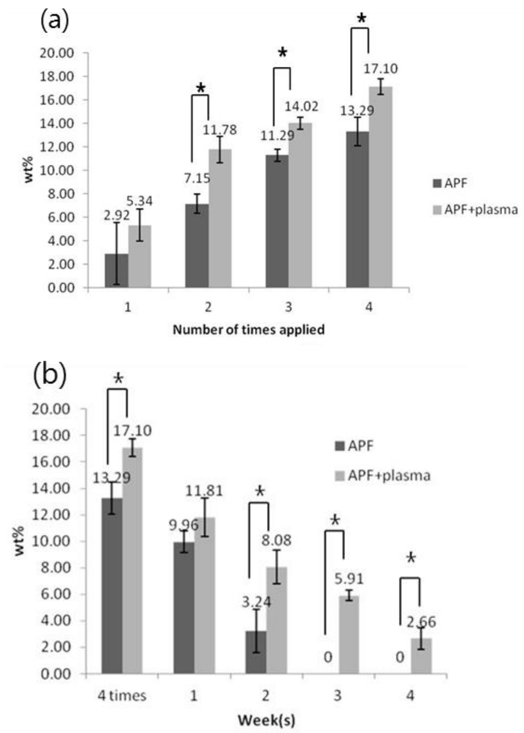

Fig. 2. (a) Mean fluoride content on the specimens surface according to the number of times. (b) Mean fluoride content when the specimens were immersed until 4 weeks after the treatment was done 4 times.

The mount of fluoride became markedly higher with increasing number of fluoride treatments in the control group and experiment group. More fluoride was measured and maintained in the experiment group than the control group. This suggests that calcium was combined with a large amount fluoride separating from the fluoride compounds due to the plasma treatment. The fluoride reduces the permeability and fluid movement of the enamel, and enhances remineralizaition. The enamel permeability has been reported to be related to the pH of fluoride. The acid fluoride enhances mineralization on the non-cavitated caries lesion surface and increases the fluoride uptake.

Many studies combining any technique, such as laser, are under active discussion. Fluoride application using a laser had a different effect according to the types of lasers and fluoride products. High intensity irradiation is required to achieve the desired effect; thus the risk of damaging the underlying pulp increases. In addition, a laser has linearity; thereby, it has some limitations when applied to the oral tissues with an irregular structure. So clinical results of fluoride application with laser irradiation are still controversial. In contrast, plasma is a forum of low temperature ionized gas. Therefore, its high degree of accessibility acts as an advantage when treating complex oral tissues. Moreover, it causes no damage to the tissue.

The results showed that the effects of plasma treatment with fluoride were maintained for a longer duration when compared with the effects of only fluoride treatment. This suggests that plasma has a higher probability of producing negative fluoride ions. Because the concentration of negative fluoride ions is an important factor for a fluoride application, it can be postulated that plasma showed a result that was maintained long-term. The existence of high-energy electrons implies a higher concentration of reactive species and more interactions among the particles. Moreover, hydroxyl radicals, which are a reactive oxygen species, interact with the surface of the tooth and can alter the surface characteristics, including hydrophilicity and hydrophobicity. The change in surface characteristics can influence the efficacy of the fluoride treatment.

The equilibrium constants of hydroxyapatite and fluorapatite at 25℃ are as follows:

(1) $Ca_5(PO_4)_3OH \rightarrow 5Ca^{2+} + 3PO_4^{3-} + OH^-$, $Ksp = 2.3 \times 10^{-59}$

(2) $Ca_5(PO_4)_3F \rightarrow 5Ca^{2+} + 3PO_4^{3-} + F^-$, $Ksp = 3.2 \times 10^{-60}$

Therefore, the equilibrium constant of the reaction that replaces the hydroxide ion with a fluoride ion is 7.2 at 25℃.

(3) $Ca_5(PO_4)_3OH + F^- \rightarrow Ca_5(PO_4)_3F(s) + OH^-$, $K = 7.2$

As the equilibrium constant (K=7.2) derived on the basis of the formula (3) is relatively large, the reaction rate becomes slow. Owing to the demand of high activation energy for this reaction, it is difficult to form fluorapatite on the enamel surface during general dental treatment. It is thought that CAP treatment provides energy exceeding the activation energy required according to formula (3), so that fluorapatite would be easily formed on the surface of tooth enamel. However, this potential mechanism needs to be verified chemically.

Based on this study's results, this study suggests that the application of fluoride and plasma to deciduous teeth is more effective and lasts longer than the method of applying only fluoride. Also, the fluoride application with cold atmospheric plasma which is safe device can be an innovative method to prevent dental caries of deciduous teeth.

4. Reference

[1] Y.M. Kim, Journal of Dental Research, **97**, 2 (2018).