

Cold Atmospheric Plasma in Dentistry

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ABSTRACT

Introduction: Plasma is the fourth state of matter and others are liquid, gas, and solid. Plasma occurs as a natural phenomenon in the universe and appears in the form of fire, in the polar aurora borealis and in the nuclear fusion reactions of the sun. It can be produced artificially which has gained importance in the fields of plasma screens or light sources. Plasma is of two types: Thermal and nonthermal or cold atmospheric plasma (CAP). Thermal plasma has electrons and heavy particles (ions and neutral) at the same temperature. Cold atmospheric plasma is said to be nonthermal as it has electron at a hotter temperature than the heavy particles that are at room temperature. Cold atmospheric plasma is a specific type of plasma, i.e., <104°F at the point of application. It could become a new and painless method to prepare cavities for restoration with improved longevity. Also it is capable of bacterial inactivation and noninflammatory tissue alteration, which makes it an attractive tool for the treatment of dental caries and for composite restorations. Plasma can also be used for tooth whitening. This review focuses on some dental application of plasma.

Keywords: Cold atmospheric plasma, Nonthermal atmospheric plasma, Plasma dentistry.

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INTRODUCTION

Sir William Crooke, a British physicist first identified the fourth state of matter in the year 1879. The name “plasma” was given by Irving Langmuir, an American chemist, in 1929. As the most common form of matter, it makes up for more than 99% of the visible universe; plasma is a collection of stripped particles. Once the electrons are stripped from atoms and molecules, those particles alter the state and become plasma. Plasmas are naturally energetic because stripping electrons uses constant energy. If the energy dissipates, the electrons reattach and the plasma

particles become a gas once again.¹ Unlike ordinary matter, plasmas can exist in a wide range of temperatures without changing state.

Based on relative temperatures of the electrons, ions, and neutrals, plasmas are classified as “thermal” or “non-thermal.” Thermal plasmas have electrons and heavy particles at the same temperature, i.e., they are in thermal equilibrium. Nonthermal plasmas on the contrary have the ions and neutrals at a much lower temperature (occasionally room temperature), whereas electrons are much “hotter.” Cold atmospheric plasma (CAP) is known to be nonthermal as it has electron at a hotter temperature than the heavy particles that are at room temperature. Cold atmospheric plasma is a specific type of plasma, i.e., <104°F at the point of application. Their sources have been introduced that offer the possibility to extend plasma treatment to living tissues.²

Non-thermal Atmospheric Plasma

Low-temperature plasma which is also known as cold plasma is used in the modification of biomaterial surfaces. Cold plasma exhibits a low degree of ionization at low or atmospheric pressure. Low-temperature plasma is created by the conversion of a compound into gas. Later it is ionized by applying energy in the form of heat, direct or alternating electric current, laser light or radiation. Argon, nitrogen, oxygen, or hydrogen are the commonly used plasma gas sources.

METHODS OF PRODUCTION OF CAP

Dielectric Barrier Discharge

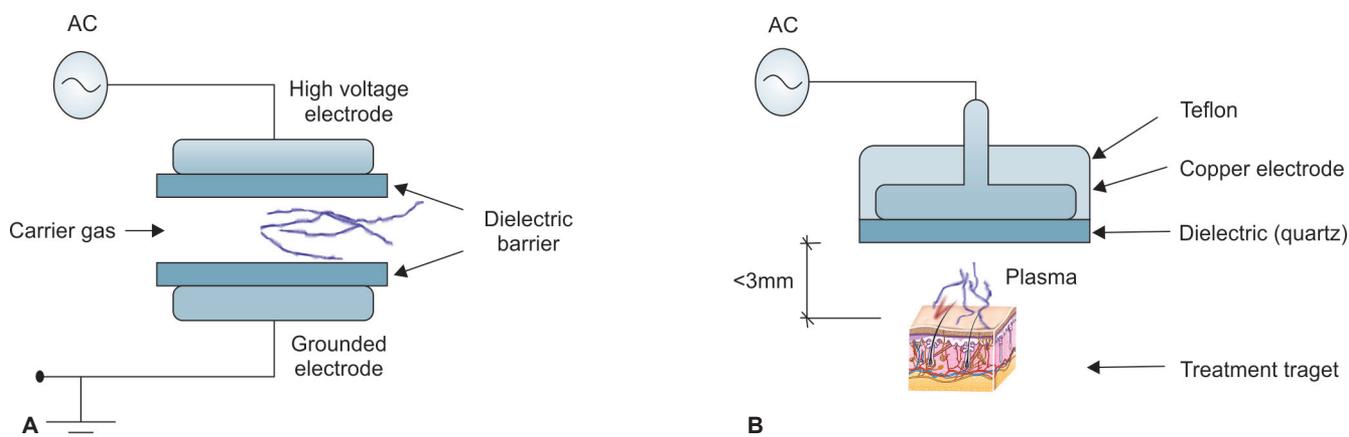
In 1857, Siemens was the first to conduct experiments on dielectric barrier discharge (DBD). The DBD consists of two flat metal electrodes which are covered with dielectric material. A carrier gas moves between the two electrodes and is ionized to generate plasma. Among the electrodes one is a high voltage whereas the other is grounded. High voltages are required to produce the discharge required to create the plasma. Alternative current (AC) high voltages generally drive DBDs with frequencies in the kHz range. The power consumption is between 10 and 100 watt.³

More recently, Chirokov et al⁴ developed the floating-electrode (FE) DBD (Fig. 1). It is similar to the original DBD and consists of two electrodes: An insulated high-voltage electrode and an active electrode. In FE-DBD the second electrode is not grounded, rather it is active—

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Figs 1A and B: Dielectric barrier discharge and a floating electrode dielectric barrier discharge (FE-DBD). (A) Formation of plasma by DBD; and (B) FE-DBD

meaning that human skin, a sample, and even an organ may be used as the second electrode. The powered electrode should be close to the surface of the second electrode (<3 mm) to produce the discharge.⁵

Plasma Jet-Radio Frequency Plasma Jets

Atmospheric pressure plasma jet (APPJ) is a kind of plasma jet which is employed for bacterial sterilization.⁶ It consists of two coaxial electrodes between which a feed gas (mixtures of helium, oxygen, and other gases) flows at a high rate. The outer electrode is grounded whereas radio frequency (RF) power (50–100 watts) at 13.56 MHz is applied to the central electrode that creates a discharge. The reactive species produced exit the nozzle at high velocity and arrives to the area, i.e., to be treated. Atmospheric pressure plasma jet has been used for the inactivation of several microorganisms.⁷

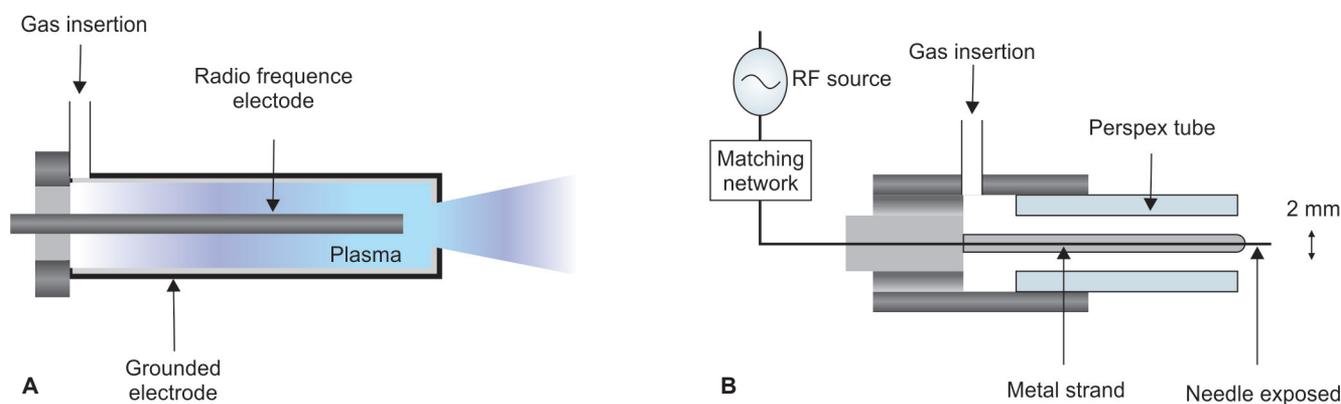
Lee et al⁸ developed the earliest RF cold plasma jet in 1992. The cathode consists of a needle electrode made of 1 mm thick tungsten or stainless steel connected to a RF source (13.56 MHz). The needle electrode is placed within a quartz tube whereas the anode is grounded. Depending on the application, helium or argon is mixed with various

gases. In 2002, Stoffels et al⁹ developed a miniature atmospheric plasma jet known as plasma needle (Fig. 2).

Pulsed Direct Current-driven Plasma Jets

Laroussi et al introduced a miniature jet that they called plasma pencil. It consists of a dielectric cylindrical tube of 2.5 cm in diameter into which two disk electrodes of the same diameter are inserted. The two electrodes are separated by a gap of 0.3–1 cm and a thin copper ring is attached to the dielectric disk. Plasma is created by applying, sub-microsecond high-voltage pulses between the two electrodes while injecting a gas through the holes of the electrodes.

When the discharge is formed, a plasma plume is launched through the hole of the outer electrode into the air. As the plasma plume (up to 5 cm in length) remains at low temperature (290 K), it can be touched safely. A high-voltage pulse generator supplies electrical power to the electrodes. The high voltage is supplied to the pulse generator by a DC voltage supply with variable output. The plasma pencil has been used in the treatment of *Escherichia coli*, leukemia cells, and *Porphyromonas gingivalis* (Fig. 3).¹⁰



Figs 2A and B: An APPJ and a plasma needle: (A) Schematic of the APPJ created by Schütze et al in 1998; and (B) schematic of the plasma needle created by Stoffels et al in 2002

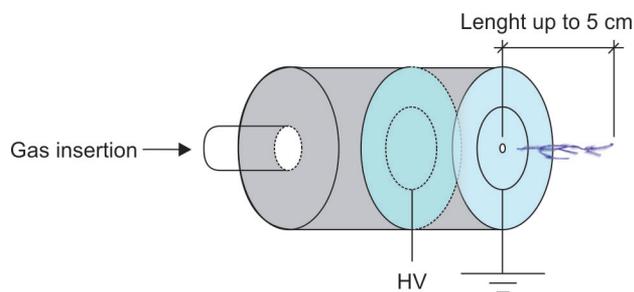


Fig. 3: A schematic of the plasma pencil created by Laroussi et al

APPLICATIONS OF COLD ATMOSPHERIC PLASMA IN DENTISTRY

Sterilization by Eradication of Bacteria

The sterilization efficacy of plasma devices depends on gas composition, driving frequency, and bacterial strain. When comparing to the conventional nonthermal methods, the plasma devices have shown to kill bacteria at higher rate.¹¹ The lipid bilayer of bacterial cell membrane contains unsaturated fatty acids and the proteins, both are involved in transportation across the membrane. The unsaturated fatty acids are susceptible to attacks by hydroxyl radicals, which are generated by plasma, destroy membrane lipids, and thereby deactivate the bacteria.

Dental Caries

Plasmas can treat and sterilize irregular surfaces, making them appropriate for decontaminating dental cavities without drilling. Although plasma is superficial, the active plasma species produced can easily reach inside of the cavity. Eva Stoffels, who pioneered this approach, suggested the use of plasma needles in the dental cavity based on the ability of plasma to kill *E. coli*.¹² Goree et al¹³ provided significant evidence that nonthermal atmospheric plasmas killed *Streptococcus mutans*.

Subsequently, a low-temperature atmospheric argon plasma brush introduced by Yang et al¹⁴ was found to be very useful in deactivating *S. mutans* and *Lactobacillus acidophilus*. They concluded that about 100% bacterial elimination was achieved within 15 seconds for *S. mutans* and in 5 minutes for *Lactobacillus acidophilus*.

Biofilms

Biofilms seen on tooth and mucosa causes caries, oral mucositis, periodontal diseases, and inflammation around dental implants. Koban et al¹⁵ showed that nonthermal plasma was more effective in treating *S. mutans* containing dental biofilm than chlorhexidine *in vitro*.

Schaudinn et al¹⁶ evaluated the biofilm removal efficacy of plasma needle *ex vivo* on root canals of extracted teeth. Teeth were divided into three groups: Treatment

with the plasma needle, treatment with 6% sodium hypochlorite (an antiseptic), and control. They concluded that 6% sodium hypochlorite was more efficient than plasma needle in removing the biofilms from extracted teeth.

Intraoral Diseases

Oral candidiasis includes *Candida*-associated denture stomatitis, linear gingival erythema, median rhomboid glossitis, and angular stomatitis. Koban et al¹⁵ and Yamazaki et al¹⁷ reported the high efficiency of *Candida albicans* sterilization using various plasmas. Their result indicates the possibility that plasma jets can be used to treat stomatitis caused by *Candida albicans*.

Root Canal Disinfection

Used a reliable and easy to use plasma-jet device, which could produce plasma inside the root canal. The plasma could be touched by bare hands and directed manually by a user into the root canal for disinfection without painful sensation. When 20% He/O₂ is used as working gas, the rotational and vibrational temperatures of the plasma are about 300 and 2700 K respectively. The peak discharge current is about 10 mA. Preliminary inactivation study results showed that it can efficiently kill *Enterococcus faecalis*, one of the main bacteria causing failure of root-canal treatment in several minutes.

Disinfection of Dental Surfaces

Rupf et al¹⁸ used atmospheric plasma jets in dental caries causing organisms. The objective of their *in vitro* trial was to analyze a microwave-powered nonthermal atmospheric plasma jet for its antimicrobial efficacy against adherent microbes. The plasma-jet treatment reduced the colony forming units by 3 and 4 log₁₀ intervals on the dentin slices in comparison to the recovery rates from untreated controls. Thus, nonthermal atmospheric plasma jets could also be used for the disinfection of dental surfaces.

Use of Plasma in Composite Restorations

Preliminary data has also shown that plasma treatment enhances bonding strength at the dentin/composite interface by approximately 60%, and with that interface-bonding enhancement to significantly improve composite performance, durability, and longevity. Current clinical practice relies on mechanical and chemical bonding. The mechanical method uses a protein layer (smear layer), which is composed of type I collagen that develops at the dentin/adhesive junction. The etching process which demineralizes the dentin allow the adhesive to infiltrate into the porous surface and this interaction gives

rise to the smear layer formation. This protein layer is responsible for the premature failure and contributes to inadequate bonding that can leave exposed, unprotected collagen at the dentin/adhesive interface, allowing bacterial enzymes to enter and further degrade the interface and the tissue.⁷

Plasma in Tooth Bleaching

Lee et al¹⁹ demonstrated that atmospheric pressure plasma in place of light sources bleached teeth by increasing the production of OH radicals and the removal of surface proteins. Furthermore, it was also shown that in combination with hydrogen peroxide, plasma removed stains from extracted teeth stained by either coffee or wine. Tooth whitening can also be achieved using a DC plasma jet and hydrogen peroxide. Intrinsic stains are a serious factor in tooth discoloration.²⁰

Park et al²¹ suggested intrinsic whitening using a low-frequency plasma source and hydrogen peroxide. Another approach by Kim et al²² used liquid plasma produced by a RF-driven gas/liquid hybrid plasma system. In this study, the RF plasma jet was placed in deionized water and the target tooth was immersed in the water. Color changes were observed on the surface of the treated tooth after 8 minutes. The OH radicals were regarded as the main cause of bleaching in this work. A nonthermal, atmospheric pressure, helium plasma jet device was developed to enhance the tooth bleaching effect of hydrogen peroxide (H₂O₂). Combining plasma and H₂O₂ improved the bleaching efficacy compared to using H₂O₂ alone. Tooth surface proteins were noticeably eliminated by plasma treatment. When a piece of tooth was added to a solution of H₂O₂ as a catalyst, production of OH after plasma treatment was 1.9 times greater than when using H₂O₂ alone. It is suggested that the improvement in tooth bleaching induced by plasma is due to the removal of tooth surface proteins and to increase OH production.²³

Post and Core

Studied the effects of plasma treatment on the shear bond strength between a fiber-reinforced composite posts and resin composite for core build-up and concluded that plasma treatment increases the tensile/shear bond strength between post and composite.

LIMITATIONS

The technique is highly technique sensitive. It does not work well in cases where amalgam restoration is present in the oral cavity. Cost of the equipment, marketing, maintenance, and availability are also some of the issues at present. Plasma needle technology has a long way to go and shall prove its applicability in the days to come.

CONCLUSION

Based on the above evidences, we can say that CAP has a bright future in dentistry due to its antimicrobial properties and its cell death properties on cells. Plasma dental treatments are basically painless, drill-less, thereby making it patient-friendly, especially in children and under-served communities, where communities, education, and familiarity with the dentist's chair are, by definition, limited.

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