DOI: 10.7860/JCDR/2014/8815.4516

Plasma Torch Toothbrush a New Insight in Fear Free Dentisry

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ABSTRACT

Dental treatment is considered painful either because of fear or anxiety. Even though fear and anxiety could be managed; the needle pricks and the heat generated with drills are both painful and destructive to the tissues of the tooth. A new technology which can reduce the pain and destruction of the dental tissues will be of huge value. Plasma torch toothbrush fits into such criteria and when developed fully, will be able to apply for many of the dental procedures for increasing the efficiency.

Keywords: Cold plasma, Fear free dentistry, Plasma, Plasma brush, Plasma jet device

INTRODUCTION

Plasma

The British physicist Sir William Crookes identified the fourth state of matter in 1879. It was termed “plasma” by Irving Langmuir in 1929. Plasma is a collection of stripped particles. When electrons are stripped from atoms and molecules, those particles change state and become plasma. Plasmas are naturally energetic because stripping electrons takes constant energy. If the energy dissipates, the electrons reattach and the plasma particles become a gas once again [1].

Physical plasma is defined as a gas in which part of the particles are present in ionized form. This is achieved by heating a gas which leads to the dissociation of the molecular bonds and subsequently ionization of the free atoms. Thus, plasma consists of positively and negatively charged ions and negatively charged electrons as well as radicals, neutral and excited atoms and molecules [2,3].

Plasma not only occurs as a natural phenomenon as seen in the universe in the form of fire, in the polar aurora borealis and in the nuclear fusion reactions of the sun but also can be created artificially which has gained importance in the fields of plasma screens or light sources.

Non Thermal Atmospheric Plasma

Low temperature plasma, also known as cold plasma, is used in the modification of biomaterial surfaces. It is characterised by a low degree of ionization at low or atmospheric pressure [4-6]. Low temperature plasma is created by the conversion of a compound into gas followed by ionization by applying energy in the form of heat, direct or alternating electric current, radiation or laser light. Oxygen, nitrogen, hydrogen or agon are the commonly used plasma gas sources.

In material science, the possible applications of low-temperature plasmas include the modification of surface properties like electrochemical charge or amount of oxidation as well as attachment or modification of surface-bound chemical groups. Consequently, properties like hardness, resistance to chemical corrosion or physical abrasion, wettability, the water absorption capacity as well as the affinity towards specific molecules can be modulated specifically and precisely by the use of low temperature plasmas [7].

Non-thermal Atmospheric Plasmas are very efficient in the deactivation of bacteria. A relatively new area is the use of these plasmas in dental applications. Plasma treatment is potentially a novel tissue-saving technique, allowing irregular structures and narrow channels within the diseased tooth to be cleaned. Low-temperature plasma is a promising method for destroying microorganisms, an alternative to conventional methods which have numerous drawbacks [1].

Mechanism of Generation of Cold Plasma

Plasmas can be produced by various means, e.g. radio frequency, microwave frequencies, high voltage ac or dc, etc. The main body of the device is made of a medical syringe and a needle. They are used for guiding the gas flow. The needle also serves as the electrode, which is connected to a high-voltage (HV) submicrosecond pulsed direct-current (dc) power supply (amplitudes of upto 10 kV, repetition rate of upto 10 kHz, and pulse width variable from 200 ns to dc) through a 60-kΩ ballast resistor R and a 50-pF capacitor C, where both the resistor and the capacitor are used for controlling the discharge current and the voltage on the needle. Because of the series-connected capacitor and the resistor, the discharge current is limited to a safety range for a human. It is found that, if the resistance of R is too small or the capacitance of C is too large, there is feeling of weak electric shock when the plasma is touched by a human [8].

The diameter of the syringe is about 6mm, and the diameter of the syringe nozzle is about 0.7mm. The needle has an inner diameter of about 200μm and a length of 3cm. Working gas such as He, Ar, or their mixtures with O_2 can be used. The gas flow rate is controlled by a mass-flow controller [8].

When working gas such as He/O_2 (20%) is injected into the hollow barrel of the syringe with a flow rate of 0.4 L/min and the HV pulsed dc voltage is applied to the needle, homogeneous plasma is generated in front of the needle. A finger can directly contact with the plasma or even with the needle without any feeling of warmth or electric shock. Therefore, this device is safe for the application of root-canal disinfection [8].

Medical Applications – An Overview

Plasma treatments can be used to improve different aspects of the therapeutic characteristics of medical implants [9,10]. Plasma processes can be used for surface coupling of antibiotic substances or for integration of metal ions into biomaterial surfaces to create implants which exhibit long-lasting antibacterial properties after implantation thereby, the often devastating effects of implant-related infections could be markedly reduced.

Plasma treatment also aids in the application of therapeutic agents onto implant surfaces as well to achieve their controlled release over time. The possible applications are drug-eluting stents and vascular prostheses which release drugs to reduce blood coagulation and thombosis as well as to prevent intima hyperplasia and restenosis.

Of late, plasma treatment has been successful in creating implants coated with therapeutic agents which aids in the attachment of the drug molecule to the implant surface or to create a layer on top of a coating with a therapeutic compound to modulate the kinetics of its release. The current research is focussed towards the equipment of implants with antibiotics and other compounds with antibacterial properties to prevent implant-related infections and the coating of anti-thrombogenic agents to prevent the formation of blood clots and thrombosis for implants with blood contact like vascular prostheses and stents. The previous studies on the drug-eluting implants, like paclitaxel and everolimus [11], dexamethasone [12] or trapidil, probucol and cilostazol [13] have aimed at reducing restenosis after implantation of vascular stents, which now, can be achieved at ease by plasma based approach.

The equipment of implants with antibacterial properties can be achieved either by attaching antibiotic substances or by creating surfaces which release metal ions which are known to have anti-infective effects. Polyvinylchloride, a polymer which is used for endotracheal tubes and catheters, was equipped with triclosan and bronopol, compounds with immediate and persistent broad-spectrum antimicrobial effects, after the surface was activated with oxygen plasma to produce more hydrophilic groups for effective coating [14]. Experiments using *Staphylococcus aureus* and *Escherichia coli* demonstrated the effectiveness of these surfaces. Similarly, polyvinylidenfluoride used for hernia meshes was modified by plasma-induced graft polymerisation of acrylic acid with subsequent binding of the antibiotic gentamycin [15].

Owing to their well-known antibacterial effects, metals like silver, copper or tin are possible alternatives to classical antibiotic compounds as an effective and sustained release from coatings is possibly easier to achieve due to their small size. Similarly to gentamycin as mentioned before, silver has been used as a powder added to a plasma-sprayed wollastonite coating on titanium implants [16-19]. Similarly, the use of copper for antibacterial implant coatings has also been studied by plasma implantation into polyethylene [20,21]. Compared to controls, the implants created by this Plasma immersion ion implantation of copper reduced the number of methicillin resistant *Staphylococcus aureus* cultivated on the respective surfaces [22]. Ion implantation can also be used for non-metals like fluorine which is of particular relevance for dental applications. This was examined with titanium, stainless steel and polymethyl methacrylate for fluorine alone [23] or with stainless steel for a combination of fluorine with silver [24].

Plasma has also found its applications in the coating of implants with antithrombogenic agents with regard to the vascular prostheses and stents which are in constant contact with blood. Thrombosis and blood clot formation are severe and potentially life-threatening complications in such cases. Classical anti-coagulants used for thrombosis prophylaxis and treatment include coumarin derivates like phenprocoumon for oral application as well as heparin for parenteral use. The Plasma-based attachment of heparin been examined for stainless steel which is used in stents [25].

Applications in Dentistry

Plasmas have been used extensively for fabricating semiconductor devices, modifying the surfaces of materials, sterilization, and other applications. Dental applications have emerged because a new version of plasma technology, so- called "non-thermal atmospheric plasmas," permits surface preparation in open air at room temperature. One of the important features of non-thermal plasma is the abundant production of reactive species in low gas temperature which includes charged particles, radiation, and reactive oxygen species. The complex components from non-thermal plasmas achieve multi-functional treatment in oral cavity. For example, reactive oxygen species and reactive nitrogen species are regarded as a key factor for sterilization, wound healing, and tooth whitening. Heat kills bacteria, but the application of this method to living tissues is dangerous. Sterilizing agents or antibiotics are used to treat human tissues that are infected by pathogens, but this may lead to pain and antibiotic resistance. Recently, non-thermal atmospheric plasmas have been shown to be highly efficient at killing bacteria in an inexpensive manner; therefore, the use of such plasmas could eliminate the problems associated with use of heat and antibiotics. The promise of plasma as a dental preparation tool is twofold, as it will both reduce tissue damage and better prepare the dental surface for composite adhesion. The promise of painless, fear-free dentistry is one of several factors motivating the plasma brush research, which the team has reported at conferences for organizations such as the International Association for Dental Research and the Society for Biomaterials [1].

Sterilization by eradication of bacteria: The sterilization efficacy of plasma devices is influenced by gas composition, driving frequency, and bacterial strain, but plasma devices have shown to kill a higher proportion of bacteria than do conventional non-thermal methods such as UV sterilization [26,27]. The mechanism of plasma sterilization is related to the abundance of plasma components, like reactive oxygen species, ions and electrons, and UV and electromagnetic fields [28]. Also, plasma can affect not only the contacted point but also the area around it. Recently, plasma sterilization has been used to treat dental diseases [29].

Yang Hong Li et al., stated that plasma sterilization, with the advantage of low temperature, fastness, thoroughness and safety, overcomes the deficiency of the traditional sterilization technology, and may become a novel method for killing microbe [30]. Autoclaves and UV sterilizers are presently used to sterilize dental instruments. To develop a dental sterilizer which can sterilize most materials, such as metals, rubbers, and plastics, the sterilization effect of an atmospheric pressure non-thermal air plasma device was evaluated by Sung et al., It was proved that the atmospheric pressure nonthermal air plasma device was effective in killing both *Escherichia coli* and *Bacillus subtilis*, and was more effective in killing *Escherichia coli* than the UV sterilizer [31].

Plasma in dental cavities: Plasma can treat and sterilize irregular surfaces; making them suitable for decontaminating dental cavities without drilling. Although, plasma itself is superficial, the active plasma species it produces can easily reach inside of the cavity. This approach was pioneered by Eva Stoffels, who suggested the use of plasma needles in the dental cavity on the basis of the ability of plasma to kill *Escherichia coli* [32]. Goree et al., provided substantial evidence that non thermal atmospheric plasmas killed *Streptococcus mutans*, a gram-positive cariogenic bacterium [33]. Sladek et al., studied the interactions of the plasma with dental tissue using a plasma needle [32]. It is an efficient source of various radicals, which are capable of bacterial decontamination; but, it operates at room temperature and thus, does not cause bulk destruction of the tissue. Raymond EJ et al., studied the interactions of the plasma with dental tissue using a plasma needle. Cleaning and sterilization of infected tissue in a dental cavity or in a root canal can be accomplished using mechanical or laser techniques. However, with both approaches, heating and destruction of healthy tissue can occur. A plasma needle is an efficient source of various radicals, which are capable of bacterial decontamination; however, it operates at room temperature and thus, does not cause bulk destruction of the tissue. From his research he concluded that plasma treatment is potentially a novel tissue-saving technique, allowing irregular structures and narrow channels within the diseased tooth to be cleaned [1].

Intraoral diseases: Oral candidiasis includes Candida-associated denture stomatitis, angular stomatitis, median rhomboid glossitis, and linear gingival erythema. Koban et al., and Yamazaki et al., reported the high efficiency of *Candida albicans* sterilization using various plasmas. Their result indicates the possibility that stomatitis caused by *Candida albicans* can be cured by plasma jets [34,35].

Root Canal Sterilisation: Lu et al., used a reliable and user-friendly plasma-jet device, which could generate plasma inside the root canal. The plasma could be touched by bare hands and directed manually by a user to place it into root canal for disinfection without causing any painful sensation. When He/O_2(20%) is used as working gas, the rotational and vibrational temperatures of the plasma are about 300 K and 2700 K, respectively. The peak discharge current is about 10 mA. Preliminary inactivation experiment results showed that it can efficiently kill *Enterococcus faecalis*, one of the main types of bacterium causing failure of root-canal treatment in several minutes [8]. Pan et al., investigated the feasibility of using a cold plasma treatment of a root canal infected with *Enterococcus faecalis* biofilms in-vitro. It was concluded that the cold plasma had a high efficiency in disinfecting the *Enterococcus faecalis* biofilms invitro dental root canal treatment.

Use of plasma in composite restorations: Preliminary data has also shown that plasma treatment increases bonding strength at the dentin/ composite interface by roughly 60%, and with that interface-bonding enhancement to significantly improve composite performance, durability, and longevity. Current clinical practice relies on mechanical bonding when it should rely on chemical bonding. The culprit that foils mechanical methods is a protein layer, the so-called “smear layer,” which is primarily composed of type I collagen that develops at the dentin/adhesive junction. To create a porous surface that the adhesive can infiltrate, current preparation techniques etch and demineralise dentin. Interactions between demineralised dentin and adhesive gives rise to the smear layer, which actually inhibits adhesive diffusion throughout the prepared dentin surface. This protein layer may be responsible, in part, for causing premature failure of the composite restoration. It 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 [1]. Kong et al., investigated the plasma treatment effects on dental composite restoration for improved interface properties and their results showed that atmospheric cold plasma brush (ACPB) treatment can modify the dentin surface and thus increase the dentin/adhesive interfacial bonding. The solution is to introduce bonds that depend on surface chemistry rather than surface porosity [36].

Plasma in Tooth Bleaching: A non thermal, atmospheric pressure, helium plasma jet device was developed to enhance the tooth bleaching effect of hydrogen peroxide (H_2O_2). Combining plasma and H_2O_2 improved the bleaching efficacy by a factor of 3 compared with using H_2O_2 alone. Tooth surface proteins were noticeably removed by plasma treatment. When a piece of tooth was added to a solution of H_2O_2 as a catalyst, production of OH after plasma treatment was 1.9 times greater than when using H_2O_2 alone. It is suggested that the improvement in tooth bleaching induced by plasma is due to the removal of tooth surface proteins and to increased OH production [37]. Nam et al., used a plasma jet on 40 extracted human molar teeth with intact crowns. The 40 teeth were randomly divided into four groups (n=10) and were treated with Carbamide peroxide + CAP, Carbamide peroxide + Plasma Arc Lamp (PAC), Carbamide peroxide + diode laser, or Carbamide Peroxide alone (control). They observed CAP was the most effective at bleaching teeth. Moreover, they observed that CAP does not damage the tooth due to its low temperature [38]. Claiborne D et al., used a plasma plume on extracted human teeth. They observed a statistically significant increase in the whitening of the teeth after exposure to CAP + 36% hydrogen peroxide gel, compared with 36% hydrogen peroxide only, in the 10 and 20 min groups. The temperature in both treatment groups remained under 80°F throughout the study, which is below the thermal threat for vital tooth bleaching [39]. In a study by Jamali and Evans results revealed that prolonged plasma treatment (without bleaching) removed some blue-stain, but the effect was small [40]. On the contrary, the combination of plasma treatment and bleaching removed most of the blue-stains. It was concluded that vacuum plasma pre-treatment and bleaching showed promise as a way of removing blue-stain.

Post and Core: Yavrich et al., studied the effects of plasma treatment on the shear bond strength between fiber reinforced composite posts and resin composite for core build- up and concluded that plasma treatment appeared to increase the tensile-shear bond strength between post and composite [1].

MERITS

Enables the dentist to perform procedures without shots and pain [1]. Reduces or avoids the use of routinely practiced painful and destructive drilling [8]. Noiseless, painless cavity preparations would be a huge advance [1].

SAFE TO USE

The flame is cool to touch without any feeling of warmth or touch [8]. It operates at room temperature and does not cause bulk destruction of the tissue, being superior to lasers [1].

LIMITATIONS

The technique is highly sensitive [41]. It does not work well in cases where amalgam restoration is present in the oral cavity [41]. Cost of the equipment, marketing, maintenance and availability are also some of the issues at present [42]. Plasma needle technology has a long way to go and shall prove its applicability in the days to come [41].

ONGOING RESEARCH

Dec 2011: Scientific research completed at the University of Missouri, Columbia.

June 2012: Clinical testing has been done at the University of Missouri College of Engineering by Qingsong Yu and Hao Li, Associate Professors of Mechanical Engineering in association with Nanova Inc. It is currently awaiting FDA approval and hoped that shortly it will be available at all dentists for the effective use.

CONCLUSION

Although, many dentists don’t believe that the plasma brush will cure all dental problems, a well-trained dentist using it may be able to do many procedures without shots and pain. Noiseless cavity preparations would be a huge advance in the general consensus. Though, dental lasers have attempted to address this concern but they have been proven to be quite expensive and slow. The problem of fear or odontophobia is more an issue with children and under-served communities, where education and familiarity with the dentist’s chair are, by definition, limited. The plasma brush may serve as an extremely valuable tool among pedodontists and as well as dentists in less-serviced communities, where individuals do not readily obtain proper dental care. With further research plasma technology can become a valuable tool in dentistry.

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FINANCIAL OR OTHER COMPETING INTERESTS: None.

Date of Submission: **Feb 06, 2014**
Date of Peer Review: **Apr 07, 2014**
Date of Acceptance: **Jun 03, 2014**
Date of Publishing: **Jun 20, 2014**