PLASMA – A POTENTIAL TOOL IN DENTISTRY

1. Dr. Sayan Das
Intern Manipal College of Dental Sciences, Mangalore,
Manipal Academy of Higher Education, Manipal, Karnataka, India.
sayandas285@gmail.com
2. Dr. Nafeesath Asfara Abdul Basheer
Intern Manipal College of Dental Sciences, Mangalore,
Manipal Academy of Higher Education, Manipal, Karnataka, India.
nafeesathasfara@gmail.com
3. Dr. Charisma Thimmaiah, MDS
Assistant Professor, Department of Pediatric and Preventive dentistry,
Manipal College of Dental Sciences, Mangalore,
Manipal Academy of Higher Education, Manipal, Karnataka, India.
charisma.t@manipal.edu
Corresponding author:
Dr. Charisma Thimmaiah, MDS
Assistant Professor, Department of Pediatric and Preventive dentistry,
Manipal College of Dental Sciences, Mangalore,
Manipal Academy of Higher Education, Manipal, Karnataka, India.
charisma.t@manipal.edu

Abstract:
States of matter include solids, liquids, gases and the fourth one is plasma, which is the most abundant and less commonly used. Plasma is a pack of energy consisting of positive ions and free electrons thus making it a potential tool not only in dentistry but also in various other fields. Based on the relative temperature of electrons, ions, and neutrons, plasma are of two types thermal and non-thermal. Non-thermal plasma is capable of bacterial inactivation and non-inflammatory tissue modification, which makes it an attractive tool for various applications in dentistry. It could be a new painless and noiseless way to prepare cavities for restoration with improved longevity, which has shown promise in several areas of dentistry and is now opening a new era of dentistry. This article is to provide basic knowledge of plasma as an emerging field and its applications in dentistry.

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INTRODUCTION

Plasma is one of the four fundamental states of matter [1]. It differs from the other three that is solid, liquid, gas by containing charged particles in it. It makes up 99 percent of universe. It is nothing but collection of stripped particles making it naturally energetic. Plasma is naturally occurring – lightning, nuclear reaction in the sun [2], nebula. But it can also be artificially made like neon light, hydrogen bomb. Natural occurring plasma is called thermal plasma that has heavy particles and electrons with the same temperature. Plasma on deionization change into gas while gas on ionization change into plasma. Plasma resembles gas outside of a container [3]. It is produced in flames, atmospheric arc. Artificially made plasma is called non-thermal atmospheric pressure plasma (NTAPP) or cold atmospheric plasma (CAP) that has heavy particles at room temperature and electrons at higher temperature [4]. CAP treatment can be used in disinfection of surfaces and treatment of living tissues with relatively less thermal or mechanical injury to the tissues as compared to lasers or antimicrobial solutions. Plasma enables painless treatment, noiseless cavity preparation, [3]. It is superior to laser as it does not cause bulk destruction of tissues [2].It operates at room temperature and the flame is cool to touch [2]. The Outstanding feature of plasma is that it works with low gas temperatures and its ability to produce high energy chemically reactive species in large amount [1].

HISTORY

Plasma was discovered by the English physicist Sir William Crookes as the fourth state of matter in 1879. But the term "plasma" was given by an American physicist Dr Irving Langmuir in 1929 [3]. Earlier in 1850s plasma discharge was used to generate ozone for the purpose of decontamination of water. In 1970s it was used in biological sterilization. With advanced researches, artificial plasma technology was developed during the mid- 1990s to make use of the unique properties of plasma [2]. By 1997 role of plasma in the field of decontamination and sterilization has expanded. In the field of dentistry, various researches are done on plasma as an antimicrobial agent to remove dental biofilms.

TYPES

Plasma are of two types: thermal and non-thermal plasma [5]. Thermal plasma occurs naturally while non-thermal plasma is made artificially. Non-thermal plasma is otherwise called non-thermal atmospheric pressure plasma (NTAPP) [4] or cold atmospheric pressure plasma (CAP) or radiofrequency atmospheric pressure glow discharge plasma (RF-APGD) [6] that differs from the thermal plasma by having heavy particles at room temperature and electrons at higher temperature. Temperature of CAP is less than 104°F at point of application. CAP can be used in the surface treatment for the modification of resistance to physical or chemical abrasion, hardness, water sorption, and wettability. Direct application of CAP also is widely used in the microbial deactivation, decontamination, root canal disinfection and also for tooth bleaching. CAP has become an alternative to other conventional methods that has various drawbacks [2].

Based on the use of plasma in dentistry it can also be classified as plasma used for surface treatment and that used for direct applications [4]. Surface treatment includes implant surface modification for improving osseointegration, increasing adhesive qualities, and polymerization, surface coating and plasma cleaning while direct plasma application includes plasma used for microbicidal activities, decontamination, and disinfection of root canal during endodontic treatment and bleaching of teeth [4].

MECHANISM OF PRODUCTION

First a compound is converted in to gas after which it is ionized with the help of energy sources like heat, direct current or alternating current, or any form of radiation, laser can be used as well. This is how low temperature plasma is formed. Some of the commonly used sources of plasma gas include oxygen, nitrogen, hydrogen, and argon [2].

Plasma generation device contains a medical syringe and a needle. The needle acts as an electrode that is connected to high voltage (10kV) direct current power supply through a resistor (60 kΩ) and a capacitor (50 pF). Due to the connection to resistor and capacitor makes the discharge current in the safety range for human [2]. Working gases like He, Ar or both of them mixed together along with oxygen is injected to hollow of the syringe flowing at rate of 0.4 L/min and high voltage direct current is applied to needle leading to the formation of homogenous plasma in front of the needle. This generated plasma is safe to touch and can be safely used for root canal treatment [2].

METHOD OF PRODUCTION OF CAP

Energy in the form of thermal, electric, or light is needed to produce and maintain plasma. Usually electrical energy is used. Some methods include: Atmospheric Pressure Plasma Jet (APPJ), Dielectric Barrier Discharge (DBD), Plasma pencil, Plasma Needle [2].

Dielectric barrier discharge

In 1857, experiment on Dielectric Barrier Discharge (DBD) was first performed by Siemens. Applications of DBD includes living tissue sterilization, inactivation of bacteria, excimer formation, surface treatment, angiogenesis [7, 8]. The dielectric barrier discharge (DBD) is made up of two metal electrodes (of which one is high voltage electrode and the other is the grounded one) covered with dielectric material. There is a carrier gas that keeps moving between the two electrodes leading to the formation ionization of the gas thus creating plasma. Plasma discharge requires a high voltage [9]. **Fridman et al.** made the discovery of floating electrode DBD (FE-DBD) [10]. In this human skin, an organ or a sample can be used as the second electrode as it is not grounded like in DBD . Here the powered electrode is kept near to the second electrode for the discharge to happen (<3mm). FE-DBD were used on endothelial cells, coagulation of blood and, melanoma skin cancer, also It has been used in Bacillus Stratosphericus deactivation, and sterilization of living tissues [11]. Plasma jets that can use DBD system were also created [2].

Atmospheric pressure plasma jets (APPJ)

APPJ is used for bacterial sterilization [12]. A feed gas flows between the two electrodes at a high rate. A discharge is created when Radio Frequency power (50-100W) at 13.56 MHz is applied to the electrode. The discharge produced comes out of the nozzle and can be applied to the area to be treated [2]. **Koinuma et al.** developed the earliest radio frequency cold plasma jet in 1992[13].

Plasma needle

Stoffels et al. in 2002 made a small atmospheric plasma jet which was called plasma [14] and a newer model in 2004 [15]. In the old model, the samples were kept enclosed in a box while in the newer model, it need not have to be placed inside a box. Plasma needle is 8 cm in length. Helium gas that has high thermal conductivity is used to create a micro discharge at the needle tip. The plasma glow generated at the needle tip is only 2 mm in diameter that makes it useful for treatment in dentistry. [16,17]. It can also be used to deactivate E. Coli [18].

Plasma pencil

Laroussi et al developed plasma pencil. It is a Pulsed Plasma Jet operated by direct current [19]. The plasma pencil has a cylindrical tube of dielectric nature which is 2.5 cm in diameter. The tube has two electrodes inside it that is separated by distance of about 0.3-1cm. One of the dielectric disk is attached with a thin copper ring. Plasma is created by passing a gas through the holes present in the electrodes and then applying high voltage pulses in between the two electrodes. After the formation of the discharge a plasma plume is inserted through the outer electrode into air. The plasma plume is safe to touch since it stays at low temperature (around 290K). It is upto 5 cm in length. The energy source to the electrode is supplied by a high voltage pulse generator. plasma pencil can be used to treat P. Gingivalis, leukemia cells, and E. coli [20].

APPLICATIONS IN DENTISTRY

Cold Atmospheric Plasma (CAP) can discharge at room temperature and can also generate plasma jet at room temperature and are having various applications. [25]

PLASMA THERAPY IN ENDODONTIC TREATMENT

CAP can be used for root canal treatment. They act as disinfecting material thus eliminating the infection and works better when compared to the conventional methods.

A study conducted by **Lu et al** used a plasma jet device that is very user friendly and can be manipulated with bare hands, hence it can be used for efficient and more effective endodontic treatment. Needless to say, it is a painless procedure, and also lead to good disinfection of the canal and kills bacteria like E. fecalis (main bacteria responsible for endodontic failure) very efficiently [3]. Another study conducted by **Pan et al**., found out that cold plasma treatment in root canal also disinfect E. fecalis biofilms [2]. **Yang et al** in their study found out that DC argon plasma brush has a bactericidal effect on S. mutans and L. acidophilus (the main pathogens of dental caries) [23]. Du et al conducted an experiment where they found out that a 5-minute treatment with cold atmospheric plasma can kill majority of E. fecalis bacteria in infected root canal and there was no difference between the treated multiple root canal system and a simple root canal [23].

PLASMA THERAPY IN RESTORATIVE TREATMENT

Studies have shown plasma treatment increases bond strength at interface between dentin and composite by around 60% hence leading to durability and longevity of the restoration [3]. Plasma treatment in restorative treatment kills a lot of disease-causing bacteria, is less painful to the patient (since drilling is not involved) and also reduces unnecessary destruction of healthy tissue. Plasma treatment is very useful for fast and contactless sterilization that can reach the small pores and narrow channels. **Yavrich et al** in their study found out that plasma treatment increases bond strength between post and composite [3].

Plasma treatment can help in preparation of cavities without drilling and decontaminate irregular surfaces and can also reach deep inside the cavity. Eva Stoffles found out that plasma can be used in the process of killing of E. coli inside the cavity [2]. **Goree et al** found out that cold plasma can also kill S. mutans [2]. **Sladek et al** found out that use of plasma needle can reduce tissue destruction since it operates at room temperature [2]. **Raymond E. J. et al** studied plasma interaction with dental tissue with the help of a plasma needle. A plasma needle constitutes of various radicals that lead to bacterial decontamination. This works at room temperature and hence does not destroy the tissues. In his research he found that plasma treatment also helps in cleaning the irregular tooth surfaces and the thin structures [3].

Plasma preparation tool is a twofold equipment since it decreases damage to the tissues and prepare the tooth surface for good composite restoration. It is also a painless procedure [3].

PLASMA THERAPY IN TOOTH CLEANSING

Pierdzioch et al. found out that used of CAP along with scaling and root planing can reduce bacteria like S. mitis more efficiently as compared to scaling and root planning alone [23].

PLASMA THERAPY IN TOOTH BLEACHING

Lee et al did a study where he found that plasma treatment also enhances the result of tooth bleaching. This is due to the release of hydrogen peroxide [3]. Helium plasma jet can be used while tooth beaching to increase its efficiency. It works because the plasma treatment reduces the tooth surface protein [2]. **Nam et al.** found out that tooth bleaching with helium DBD plasma jet along with 15% carbamide peroxide and 5.4% H_2O_2, gives more effective result than conventional light source and also need lesser concentration of H_2O_2 and also low thermal damage is seen. There is also no alteration of the mineral composition of the teeth due to the use of plasma [23].Hence CAP can be beneficial for bleaching as well.

PLASMA THERAPY IN TREATMENT OF ORAL BACTERIAL INFECTIONS

CAP also helps in development of new drugs for the dental tissue. New biomedical effects by ions and newer plasma drug can be developed that operate at cellular level [1]. P. gingivalis in a 15-micrometre film (equivalent to 30 layers of P. gingivalis) when treated for 10 days with APNP jet, deactivates all the bacteria throughout the entire thickness [24]. **Koban et al.** and **Yamazaki et al.** found out that stomatitis caused by Candida Albicans can be cured by plasma jets [2].Oral Bacterial Deactivation can be

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done Using a Low-Temperature Atmospheric Argon Plasma Brush. Low temperature atmospheric argon plasma brush decontaminates bacteria like S. mutans and L. acidophilus [2].**Daeschlein et al.** found out that argon CAP can limit multidrug resistant bacteria microbial colonization [23]. It has been seen that the reactive species generated from cold plasma cause death/damage to the cells through dehydration or lysis of the membrane [9] and also damages DNA, lipids and proteins [26,27]. Plasma plumes can also reach inaccessible sites (like periodontal pockets and interproximal caries) and hence is better than conventional therapies to get rid of the biofilms [28]. As compared to conventional therapies, atmospheric pressure cold plasma is better in a way because there is less chances of bacterial resistance since there is different kinds of active agents and its multiple mode of actions [29,30].

PLASMA THERAPY ENHANCES RATE OF WOUND HEALING

Recent studies have also revealed that cold atmospheric plasma accelerates the process of wound closure .**Kwon et al.** found out that the mRNA expression of growth factor in gingival fibroblasts can be increased by air DBD plasma treatment resulting in enhanced gingival wound healing [23].

PLASMA THERAPY IN POST IMPLANT ABNORMALITIES

Shi et al conducted an experiment of peri-implantitis near 4th mandibular premolar region of a beagle dog. The experiment showed that combination of the conventional periodontal techniques with CAP resulted in higher bone level and also reduces bacteria (like P. gingivalis, Tannerella Forsythia) [23].

PLASMA IN DENTIN BONDING.

RF-APGD plasma effectively improves the mechanical strength of dentin collagen and enhances the strength of bond at dentin-resin interface [25]. **Chen et al.** found that the treatment of cold plasma brush on dentin surface increases the hydrophilicity and permeability of dentin which enhances the bonding strength with dentin [23].

PLASMA IN VENEERS

Use of CAP along with veneers gives better wettability of the ceramic surface, which helps the adhesives to penetrate deeper which result in higher bond strength of the veneers [31,32].

Though there are a lot of advantages of using plasma in dentistry, there are few limitations such as it is technically sensitive and high cost of the equipment. [2]. Cold DBD plasma treatment can lead to promotion or inhibition of endothelial cell mediated angiogenesis. Hence CAP treatment can be referred to as a double edged sword [23]. Higher dose or longer application of CAP may negatively affect the health of the patient and in turn be lesser therapeutic [33].

CONCLUSION

CAP due to its antimicrobial effect and cell death properties have great future prospect in dentistry and oncology as well. It gives promising results in teeth bleaching, conservative and endodontic treatment, and a lot more. Compared to laser CAP is an even better method as laser is more expensive and the process gets slower with laser. These are also more useful of children who have odontophobia and is difficult to treat such patients by conventional therapy. CAP is hence definitely a better and more advanced technique of dental treatment making the process easier for both the dentist and the patients.

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