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Aurora Borealis a new dimension in dentistry

Dr. Siddharth Jigyasoo[1], Dr. Pooja Kabra[2], Dr. Ekta Choudhary[3]

[1]Post graduate student, Department of Conservative dentistry and endodontics, SDS, Sharda University

[2]Associate Professor, Department of Conservative dentistry and endodontics, SDS, Sharda University

[3]Professor and Head, Department of Conservative dentistry and endodontics, SDS, Sharda University

Corresponding Author: Dr. Pooja Kabra, Associate Professor, Department of Conservative dentistry and endodontics, SDS, Sharda University, Greater Noida, pooja.kabra@sharda.ac.in

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Abstract

The recent enormous progress in understanding of plasma physics and development of plasma has attracted focus on the application of plasma in medicine and dentistry. Active plasma ions, electrons, and photons have the ability to activate and control various biochemical procedures. Nonthermal plasma (NTP) is widely used for various therapeutic applications in health care. Particularly in dentistry, NTP holds big potential such as for bacterial inactivation, efficient sterilization, and treatment of dental caries. This review article intends to provide information on potential NTP applications in dentistry.

Keywords: Non thermal plasma, therapeutic applications, sterilization

1. Introduction

The advent of new technology has caused significant changes in the field of dentistry, enabling dentists to provide more efficient and effective treatments to their patients. The application of technology in dentistry is not just limited to diagnosis and treatment. It has also made dental care more accessible and affordable, especially for underserved populations. In this article, we discuss the influence of plasma in dental care from a public health perspective. 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.

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. Based on relative temperatures of the electrons, ions, and neutrals, plasmas are classified as "thermal" or "nonthermal." 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. CAP sources with <40 °C temperature at the point of application have been introduced that offer the likelihood to treat human beings.

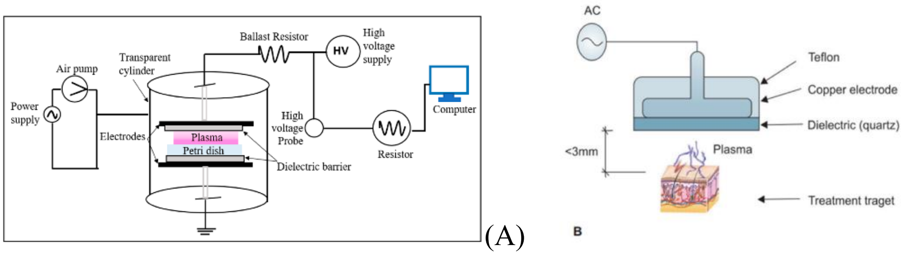
2. METHODS OF PRODUCTION OF CAP

Several different types of CAP have been developed for biomedical uses. Energy is needed to produce and maintain plasma. Thermal, electric, or light energy can be used. Some methods used to produce CAP include:

A) Dielectric Barrier Discharge (DBD)
B) Atmospheric Pressure Plasma Jet (APPJ)
C) Plasma Needle, and Plasma Pencil

Dielectric Barrier Discharge (DBD)

In 1857, Siemens was first to conduct experiments on Dielectric Barrier Discharge (DBD). DBD has many applications including: sterilization of living tissue, bacteria inactivation, angiogenesis, surface treatment, and excimer formation. Di-electric covering two-level metal terminals is available in DBD (Fig. 1A). One is a high voltage, and another is a grounded electrode. Gas passing between electrodes is ionized and plasma is formed. A high voltage alternative current is required, and power consumption is 10–100W. DBD with input power in the W range have also been often reported for biomedical applications.[6] A variety of electrodes is possible, like dielectric material covering just a single electrode rather than two and a cylindrical electrode is present instead of flat. Another variant, as shown in Fig. 1B, is the floating electrode DBD (Fe - DBD), which was developed by Fridman et al. It comprises a high voltage electrode and another active electrode like human skin and organs. The powered electrode ought to be put close (<3 mm) to the second electrode to create plasma.[3]

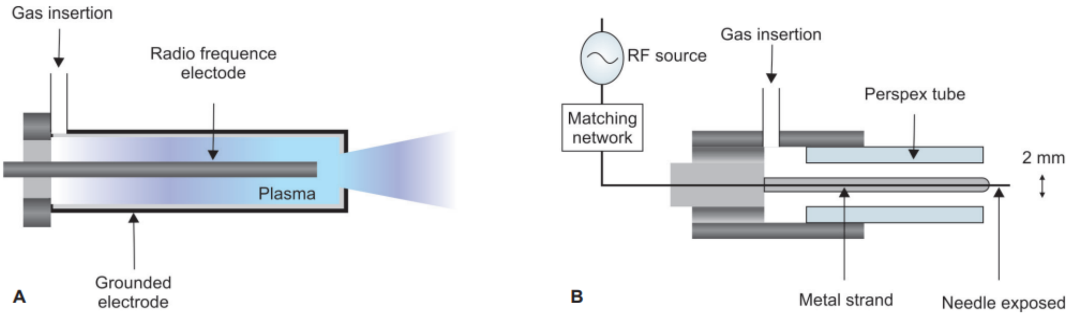


(A) (B)

Fig.1. Generation of plasma by different techniques: Dielectric barrier discharge (DBD) and a floating dielectric barrier discharge (FE-DBD). (A) Formation of plasma by DBD; and (B) FE-DBD.

Atmospheric plasma pressure jet (APPJ)

Atmospheric Plasma Pressure Jet (APPJ) are the plasma jets having the gas temperature ranges from 25–200 °C with a charged-particle density of 1011–1012 cm−3 and reactive species at high concentrations, i.e., 10–100 ppm . It can be made up with different setups in which a gas mixture (helium, oxygen, and other gases) is pushed to flow quickly between two electrodes. One of the common setup is shown in Fig. 2A where a radiofrequency of 13.56 MHz at a power of 50–100 W is applied on the discharge creating a central (cathode) electrode, and the outer electrode (anode) is grounded. The cathode is made of tungsten or stainless steel with 1 mm diameter (Fig. 2A).[3]



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

Plasma needle and Plasma pencil

Stoffels et al. invented a miniature atmospheric plasma needle in 2002. Fig. 3 shows a schematic representation of the same. In 2004, a new version was developed. The new plasma needle has a 0.3 mm diameter metal support with a perspex tube with a sharpened tip. When radiofrequency power ranging from 10 mW to several watts is delivered at 13.05 MHz, microplasma is produced. Microplasma is effective for treating tiny regions in dentistry that requires attention. E. coli bacteria can be killed by this process.[3]

Plasma pencil can be used to inactivate P. gingivalis and E. coli bacteria. These bacterial strains have been reported to exhibit biofilm formation leading to dental caries. Inactivation of plankton bacteria by plasma pencil also provides opportunity to inhibit the biofilm formation. Moreover, it can also be an approached technique for the curation of leukaemia.[3]

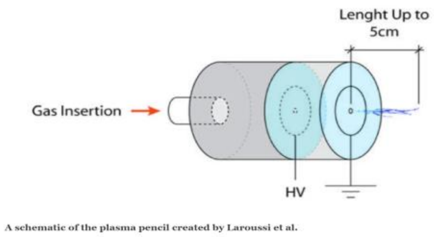


Fig.3 Figure representing plasma needle designed by Laroussi et al.

3. MECHANISM OF ACTION

The release of reactive oxygen and nitrogen species, i.e., ROS and RNS free radicals and reactive species, Metastables, and UV light form the basis of the mechanism of action of plasma irradiation.[2]

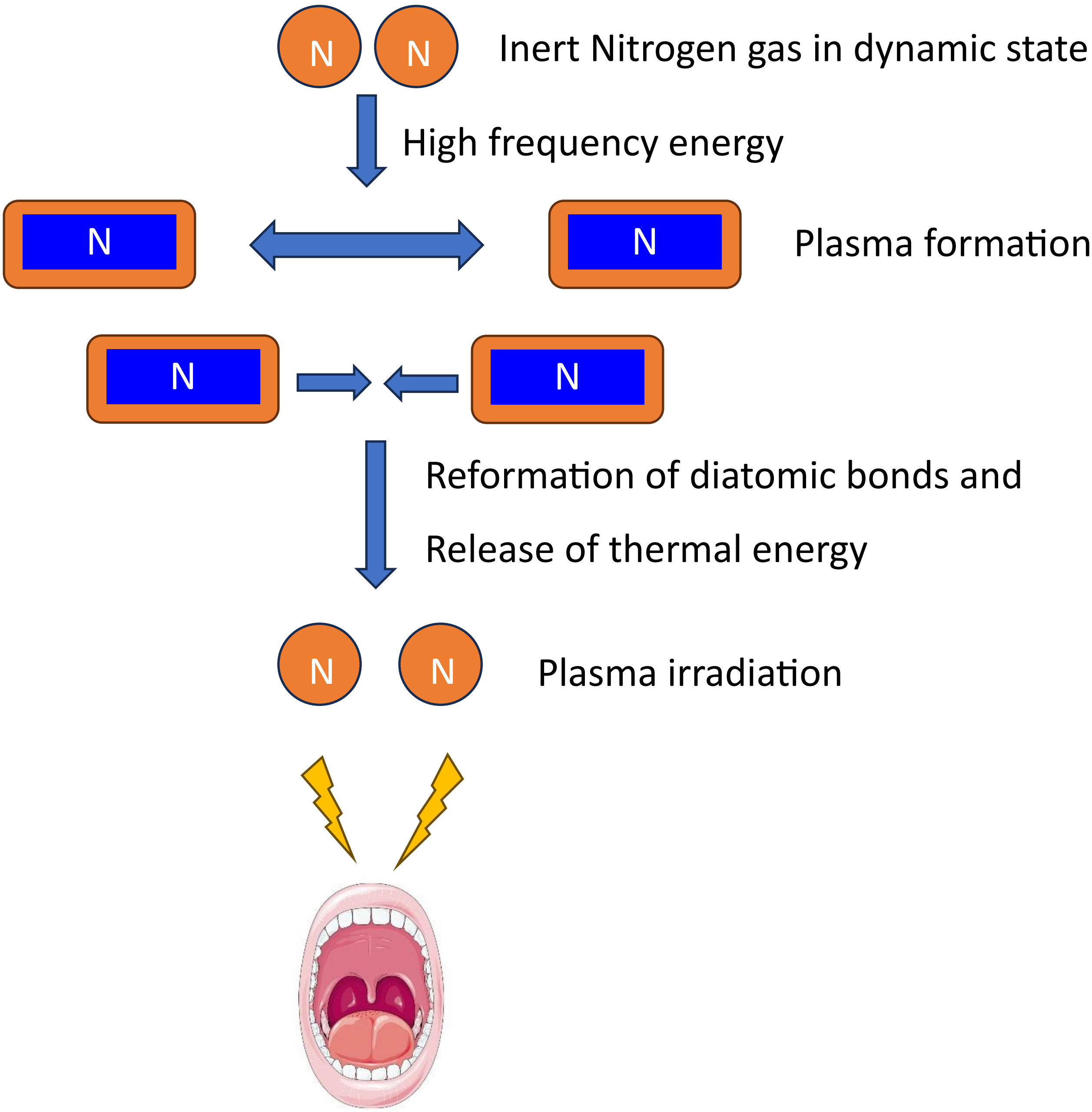


Fig.4 Depicting generation of plasma for irradiation onto the oral tissues

4. Applications of CAP in Dentistry

A. Sterilization by Eradication of Bacteria.

Sterilization is the process of killing all microorganisms, including viruses, bacteria, fungus, and bacterial endospores.[3] 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.[7]
Sung et al. also used CAP to assess the sterilization effect on dental instruments. They inoculated B. subtilis and E. coli on diamond burs and polyvinyl siloxane materials. Then they exposed them to the plasma for a different length of time (from 30 to 240 seconds). They compared the plasma device efficacy with the UV sterilizer. The plasma device decreased the colony-forming unit (CFU) for both E. coli and B. subtilis significantly on both diamond burs and polyvinyl siloxane materials. The atmospheric pressure of non-thermal air plasma showed better sterilization rates than the UV sterilizer.[3]
Whittaker et al. has suggested that use of plasma gas cleaning may be very effective in decreasing the absolute amount of proteinaceous substances from pulp that may be transferred between the patients when endodontic instruments and files are used.[16]

B. Dental Caries.

Mechanical or laser methods can be used to clean and disinfect infected tissue in a tooth cavity or a root canal. Both methods, however, have the potential to heat and destroy healthy tissue. The generation of heat, vibrations and noise may increase the pain perception of patients as well as their anxiety and fear of dental treatment. When used in dental cavities, cold plasma decontaminates the cavities without the need to drill them. Despite plasma's surface-level nature, its active plasma species can penetrate deep into 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.[18]
Goree et al provided significant evidence that nonthermal atmospheric plasmas killed Streptococcus mutans.[15].
Yang et al. introduced nonthermal argon plasma brush which is highly efficacious in the deactivation and decontamination of L. acidophilus and Streptococcus mutans. The authors revealed that approximately 100% of bacterial decontamination was achieved within 15 s for S. mutans and within 5 min for L. acidophilus.[10]

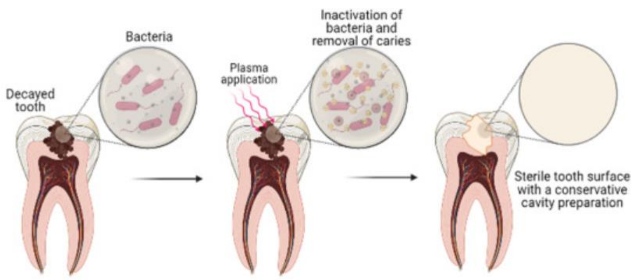


Fig.5. Showing application of plasma in removal of caries .

C. Biofilms.

Bacterial biofilms are made up of adhering consortia of microorganisms encased in self-produced polymer matrixes made up of polysaccharides, proteins, lipids, and extracellular DNA. Biofilms may grow on nearly any living or non-living surface. Dental biofilms are important etiological components in dental illnesses that are a global public health concern. Microbial succession and maturation occur if the dental biofilm is kept undisturbed. When the biofilm undergoes this transformation, its bacterial makeup shifts from cocci to filamentous organisms to spirochetes, and from gram-positive bacteria to gram-negative bacteria.[3]
As a result, biofilms grow on teeth and other surfaces in the mouth, including the tongue. Caries, gingivitis, periodontitis, oral mucositis, and peri-mucositis, and peri-implantitis are all caused by the acquisition of bacteria and the growth of the biofilm microbiota.
Koban et al showed that nonthermal plasma was more effective in treating S. mutans containing dental biofilm than chlorhexidine in vitro.[11]
A recent study evaluated the effect of a gas mixture of He and O2 plasma applied on ex vivo E. faecalis biofilms. These biofilms were grown inside single-root teeth. Thus, Saleewong et al. evaluated the plasma effect with a gas flux of 0.5 L/min in 54 teeth. The dental elements were allocated to five experimental groups (NaOCl, NTPP, NaOCl + NTPP, only the gas, and the negative control). The results demonstrated a significant reduction when using the NTPP for 5 min, or for 1 min in association with NaOCl (5%). Moreover, the association of both decontamination techniques led to a greater depth level of decontamination in the dentin.[5]

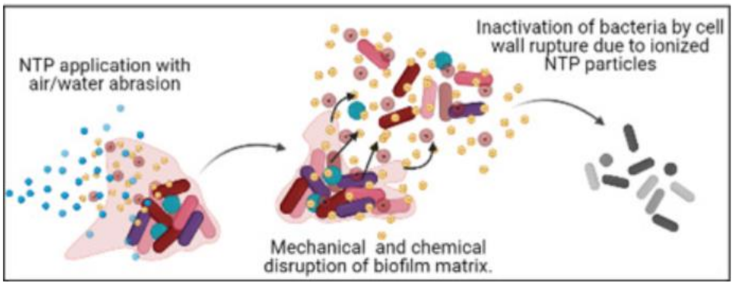


Fig.6. Application of Non-thermal plasma for disruption of biofilm on surface of teeth .

D. Root Canal Disinfection

Root canal disinfection is the most important step of root canal therapy. Cleaning and sanitizing the canal's walls and the lumen is critical to achieving a good treatment outcome. Canals with bacterial infection are known to fail. This means germs that remained in a canal after chemical and mechanical preparation must be maintained to a minimum to provide successful therapy and treatment. The 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. Recently a novel disinfecting system has been tested using non-thermal plasma for the disinfection of root canal systems, which overcomes the drawbacks of the conventional methods, yet has the potential to achieve a greater amount of disinfection.[3]
, Lu et al. created the "Model RC-1" plasma jet apparatus. An 8 kV, 500 ns pulsed direct current with a pulse frequency of 10 kHz was used to power the device. At a flow rate of 0.4 slm, a gas combination of 80 % He and 20 % O2 was injected into the syringe. The needle, which had an inner diameter of 200 m, was used as the electrode. Hence, the needle could be easily inserted

into the root canal system to generate a very narrow plasma plume, producing effective root canal disinfection.[14]

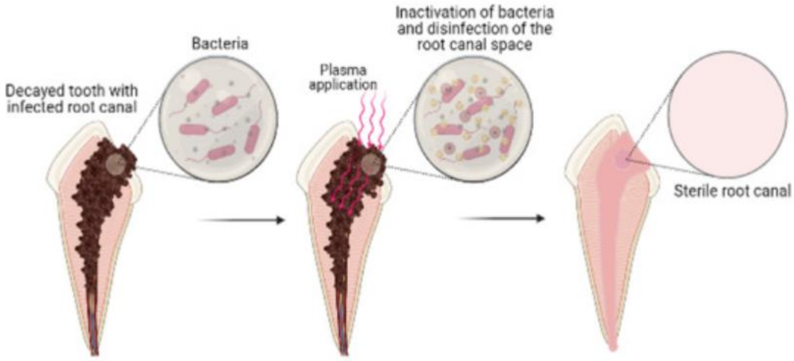


Fig.7. Application of plasma in Root canal disinfection of an infected tooth. Once a root canal is opened, it is treated with plasma for a specific time for the microbiota disinfection.

E. Plasma in Tooth Bleaching

Teeth that were discoloured and had no pulp were bleached for the first time in 1864 using a range of medicines, including chloride and other hypochlorite-based agents as well as sodium perborate and hydrogen peroxide[3]. Researchers have been interested in the use of CAP in tooth whitening. Hydrogen peroxide is currently used to whiten teeth. Hydroxyl radicals generated from Hydrogen peroxide play the main role in tooth bleaching.

Some researchers looked for an alternative treatment and found CAP to be an interesting candidate. They either used it in complement with the hydrogen peroxide treatment or alone. Lee et al 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.[3]

Lee et al. described the use of NTP for teeth bleaching. When atmospheric pressure plasma is used with hydrogen peroxide, OH radicals are released, and surface proteins are removed [13]. Nam et al. employed a plasma jet to bleach teeth in in-vitro research. It consisted of forty human molar teeth that had been removed and had their crowns intact. n ¼ 10 teeth were randomly separated into four groups and treated with carbamide peroxide þ plasma arc lamp (PAC), carbamide peroxide þ CAP, carbamide peroxide þ diode laser, or carbamide peroxide by itself (control). The authors discovered that CAP, rather than carbamide peroxide alone or a combination of carbamide peroxide and diode laser, was the most successful in tooth bleaching without causing dental damage.[8]

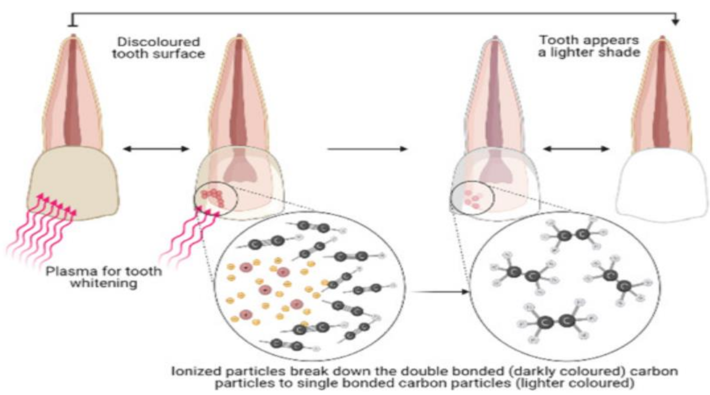


Fig.7. Application of plasma for bleaching of tooth

F. 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.
As Costa Dantas et al. observed, plasma treatment enhanced the post's wettability.[9]
In their study, Ye et al. found that non-thermal plasma therapy caused post-surface aging. After being treated with plasma, the fiber posts were exposed to air for 1 h or more, and the bond strength improved.[12]

G. Intraoral diseases
Candida albicans causes denture stomatitis, angular stomatitis, median rhomboid glossitis, and gingival erythema. Koban et al. and Yamazaki et al. reported that plasma jet can cure these diseases which are caused by C. albicans.
CAPP had antifugal modulatory effects on Candida albicans virulence factors such as adhesion, filamentation, and reduction of ergosterol production, which were scientifically proven in vivo in a mouse model.[4]

Therefore, NTP has the potential to treat several intraoral diseases, however, extensive research is required incorrectly determining its effects on a large variety of oral and dental diseases.

H. Implant modification
Modification focuses upon the interaction of implant to body fluid which helps in bone healing. Plasma increases surface roughness and wettability which help in cell adhesion[17]
It is known to aid in osteoblastic proliferation and osseointegration, thus increasing the success rates of implants. One of the advantages of using plasma is that no residue is present after plasma treatment. Some physicochemical characteristics were changed like surface free energy, functional hydroxyl groups, component of hydrocarbon. We conclude that cold plasma treatment immensely increases the success rate of implants as it helps in increasing the integration of the implant within the alveolar socket.[3]

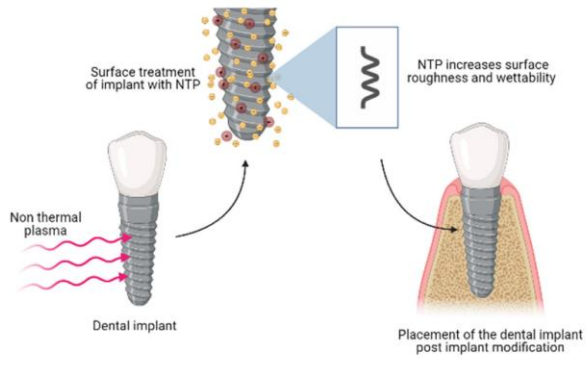


Fig.8. Application of plasma for implant modification

5. 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.[6]

6. 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. As plasma dental technology advances, this misunderstanding will certainly be clarified up shortly. As a result of the availability of hand-held equipment designed for clinic use, the method is expected to increase in popularity. Researchers and doctors might potentially benefit from a better knowledge of the cellular and molecular mechanisms involved.[6]

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