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PLASMA EMPOWERING DENTISTRY

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ABSTRACT
Plasma which is considered to be the fourth state of matter is a cloud of proton, neutron and electron. Due to the use of constant energy by stripping electrons, plasmas are naturally energetic. Plasma is of two types: thermal and non-thermal (NTP) or cold atmospheric plasma. Electrons and heavy particles are present at the same temperature in Thermal plasma. Cold Atmospheric Plasma (CAP) is non-thermal because it has electron at a hotter temperature than the heavy particles that are at room temperature. Active plasma ions, electrons, and photons have the ability to activate and control biochemical procedures. CAP has the power to cause deactivation of microorganism, death of cancer cell, detachment of cells. For this reason there have been attempts to apply plasma technology and find effectiveness of CAP in various fields of dentistry such as surface modifications of dental implants, enhanced adhesion of restorative materials, sterilization of endodontic files and other surgical instruments, root canal disinfection, polymerization of composite resin, post surface treatment, tooth bleaching. Therefore CAP has a bright future in dentistry. This review article demonstrates contemporary aspects of plasma application in dentistry.

KEYWORDS: Cold Atmospheric Plasma, Thermal Plasma, Dielectric Barrier Discharge.

INTRODUCTION
Plasma, by far the most dominant state of matter in the universe, was identified by British physicist Sir William Crooke in 1879. He wrote: "...The phenomenon in these exhausted tubes reveal to physical science a new world, a world where matter may exist in a fourth state ...". Irving Langmuir, an American Chemist in 1929 applied the name “PLASMA”. Plasma has played an essential role in various industries and has become an integral part of our lives.[1] Meghnad Saha, an Indian physicist, estimated that more than 99% of the universe is

composed of plasma. Examples of plasma in nature are the solar corona, stars, aurora and lightning. Fluorescent lamps, neon advertising signs and plasma display panels (PDPs) are typical examples that use the ultraviolet light emitted from plasma.[1] Computers, cellphones and various types of display panels would not be able to be produced without plasma technology. Recently, plasma has attracted increased attention in the biomedical field. The first application of plasma in dentistry occurred in the manufacturing process of dental instruments or the disinfection of them.[2] Nevertheless, Eva Stoffels is believed to introduce the first investigation with the view of a possible therapeutic approach for dentistry which can be mainly subdivided into two principal approaches: one is the use of plasma technology for the treatment of surfaces, materials or devices, and the other is the direct plasma application on or in the human body for therapeutic purposes like tooth bleaching, root canal disinfection.[17]

The matter has four state- solid, liquid, gas, and last one is plasma. **Plasma is a partially ionized gas containing cloud of proton, neutron and electron.** When a gas is given more energy, particles of the gas collide with each other.[2] As a result, electrons and ions are produced and the gas has electric charge. Particles whose electrons are taken away from their atoms can become a state of plasma. A continuous flow of energy is needed to tear off electrons from their atoms. If the energy is lost, then the electrons can reattach and the plasma gets converted to gas once again. The boundary between gas and plasma is not clear. Gases are usually electrical insulators. When gas becomes plasma, it contains a roughly equal number of positive and negative particles in addition to neutral particles.[2,3] The increased used of plasma has been attributed to its techniques that are contact-free, pain-less, self sterilizing and non invasive. Because Non Thermal Plasma (NTP) does not lead to increase in temperature at the point of application, it does not cause any thermal damage and pain in patients. Its application allows for the treatment of heat sensitive, non-homogenous surfaces and living tissues. Medical applications include anti-itch property, broad-spectrum antimicrobial technology, anti-inflammatory, tissue-stimulating, blood flow-enhancing, and proapoptotic effects, enhancement of wound healing by increasing cutaneous microcirculation, monocyte stimulation, and keratinocyte proliferation.[3] Plasma can combat tumour growth by increasing the efficacy of antitumour therapeutic agents, reactivating apoptotic pathways, or down-regulating growth-related gene sites.

It prevents the wear of instruments especially in case of Implants as plasma cleaning leaves no residue, and, when optimized, generates only CO_2, H_2O, and N_2 as gaseous waste which do not corrode the surface. Plasma has potential to inactivate microorganisms associated with oral diseases.[3] Studies have shown that bacterial DNA is destroyed by cold plasma. 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 which act on the bacterial DNA. But along with advantages comes certain limitations like this technique is highly sensitive and needs precision by the operator to avoid casualties. It does not work well in cases where amalgam restoration is present in the oral cavity. During sterilization spores are difficult to inactivate due to the limited penetration depth of cold plasma.[4] Equipment is expensive and maintenance and availability are problematic. Inspite of all limitations Cold Atmospheric Plasma has a bright future in dentistry due to its multiple applications in various treatments.

Classification of Plasma

On the basis of relative temperatures of the ions, neutrons, and electrons, plasmas are categorized as “thermal” or “nonthermal.”[3,4]

Thermal Plasma: Electrons and heavy particles of thermal plasma remains in thermal balance with each other. Thermal plasmas are natural phenomena. Hot plasma techniques in the form of electrosurgery and coagulation have been used in medical sciences for a long time to achieve hemostasis.[5]

Non Thermal Plasma (NTP): The ions and neutrons here are at a much lower temperature (sometimes room temperature), whereas electrons are much “hotter”. Recently, NTP source with <40°C or less than 104 degree F temperature at the point of application have been presented that offer the possibility to treat human beings.[3] Cold Atmospheric Plasma (CAP) is known as non-thermal because it has electrons at a higher temperature than the heavy particles that are at room temperature. In such plasmas electron temperatures can be 100 to 1000 times higher than in neutral gas temperature. In this way light and energetic particles (electrons) create a chemically reactive medium, while the gas is sustained at room or slightly elevated temperatures and thermal damage to the surroundings is avoided. Cold atmospheric plasma (CAP) is characterized by a low degree of ionization at low atmospheric pressure. Non Thermal Plasmas are artificially made, the composition and temperature of which are adjustable. Gases that can be used to produce CAP are Helium, Argon, Nitrogen, Heliox (a mix of helium and oxygen), and air.

Generation of Plasma

At a high pressure or near atmospheric pressure, the collision frequency is enough to establish partial local thermodynamic equilibrium and, as a result, thermal plasmas are likely to occur. If cold plasmas are generated at atmospheric pressure, the process can be simplified and productivity can be increased.[5] For these reasons, non-thermal atmospheric pressure plasmas have recently garnered attention not only in industry, but also in the biomedical field. Plasma is a collection of stripped particles. When electrons are stripped from atoms and molecules, those particles change state and become plasma. For the production of plasma, a maintained flow of energy is required.

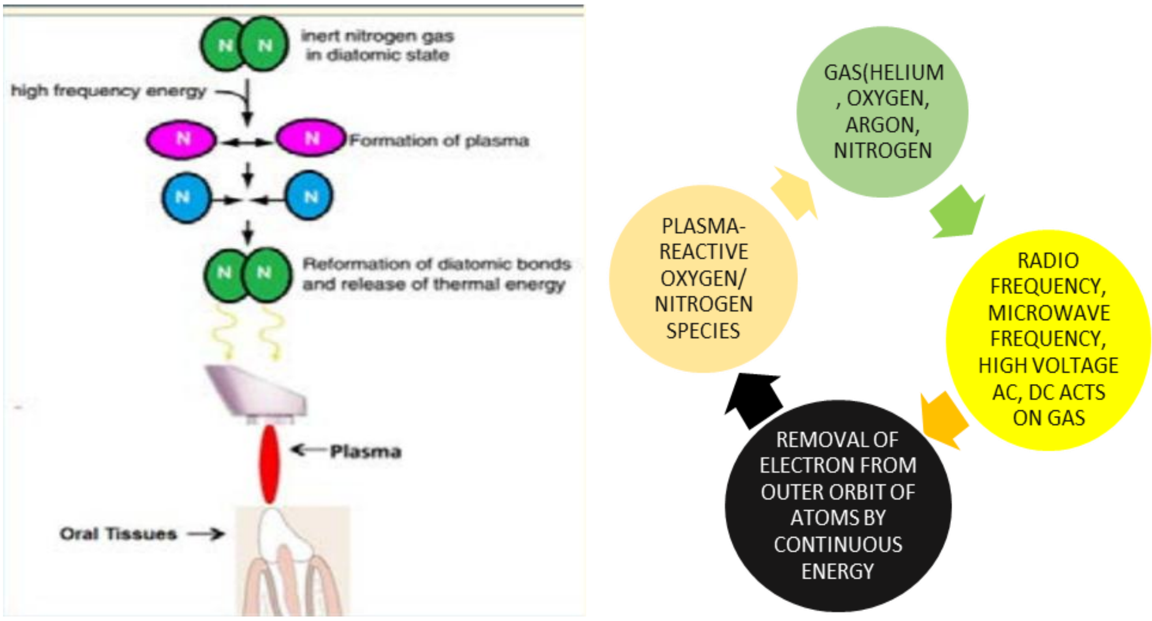


Fig 1: Shows Nitrogen gas being acted upon by high frequency energy to cause dissociation of gas by stripping of electrons and generation of plasma.

The discharge needed to produce Cold Atmospheric Plasma can be induced electrically or through light energy or even through thermal energy. Presence of electromagnetic field supply energy can also help the gas to sustain plasma state. Electrons are accelerated by the electromagnetic field much faster, but are less effective to transfer their energies to heat their environment than heavy ions.[5] Accelerated electrons results into ionization of particles, radiation, and creation of reactive species.

Devices Producing Plasma

Plasma can be produced by radio frequency, high voltage alternating current (AC) or direct current (DC), microwave frequencies. When the electrons in a plasma are displaced from their equilibrium positions, strong electric fields are set up between the negatively charged layers and the background positive layers. These electric fields tend to restore the initial neutral condition by bringing the particles back to their original positions. As a result, the more mobile electrons oscillate with a certain frequency known as the plasma frequency. If these oscillations propagate, we get the electron plasma wave, also known as the Langmuir wave. It is a high-frequency wave and is electrostatic in nature.[3,5]

Direct barrier discharge (DBD): First DBD experiment was conducted by Siemens in 1857. This technique is used during sterilization of living objects, angiogenesis, surface treatment, excimer formation and deactivation of Bacillus stratosphericus. Dielectric barrier discharge (DBD) sources consist of two parallel-plate metal electrodes, where one or both of the electrodes are covered by a dielectric material. The frequency of an applied high voltage is in the kHz range. In electric fields, dielectric materials can be polarized and sustain electric charges on their surfaces.[5] Examples of dielectric materials include ceramic, glass, out of the two electrodes one is high voltage and another is grounded electrode. Gas passing between these electrodes is ionized and plasma is formed. The power electrode should be placed close (< 3 mm) to second electrode to produce plasma. DBD also used on melanoma skin cancer, endothelial cell and

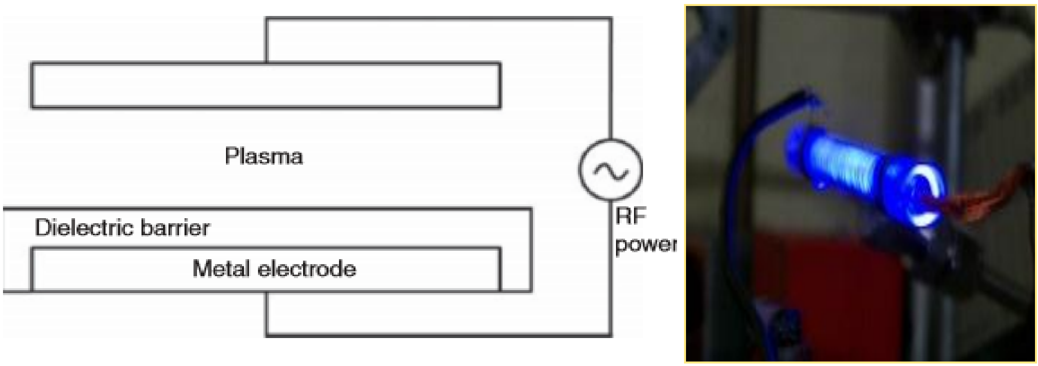


Fig. 2: Schematic Diagram of a Dielectric Barrier Discharge.

Atmospheric pressure cold plasma jet

If the generated plasma is launched outwards, it can be applied to the intended sites of a subject. The plasma that is generated in a reactor and launched into open space is called a ‘plasma jet’ or ‘plasma plume’. Plasma jets are blown from reactors by the flow of working gases. The flow rates of working gases are typically several standard liters per minute (slm). Various types of plasma jet devices have been developed in recent years. One is the atmospheric pressure plasma jet (APPJ). The APPJ consists of two coaxial electrodes between which a working gas(Helium, oxygen and other gas) flows.[5,6] Cathode is made of tungsten or stainless steel with 1 mm diameter. The APPJ has been studied for inactivation of spores of Bacillus globigii. Because atmospheric pressure cold plasma jets can be applied to intended sites in open space without damaging surrounding tissues, they have the most potential in the biomedical field.

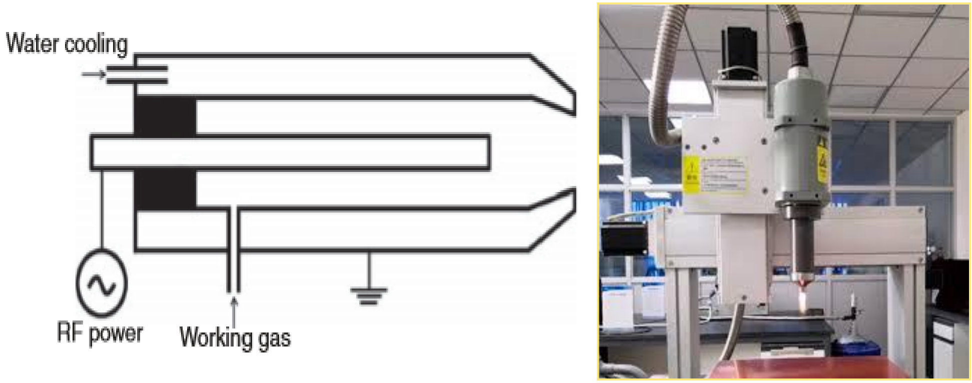


Fig. 3: Schematic Diagram of Cold Plasma Jet.

Corona discharge

If a wire or pointed tip-shaped electrode is substituted for one of two parallel-plate electrodes, a high intensity local electric field is generated around the tip.[6] Therefore, plasma can be generated at a relatively low voltage at atmospheric pressure. Since the lighting plasma around the tip looks like a crown, this discharge is called corona discharge. The corona discharge is unstable and restricted to a small area.

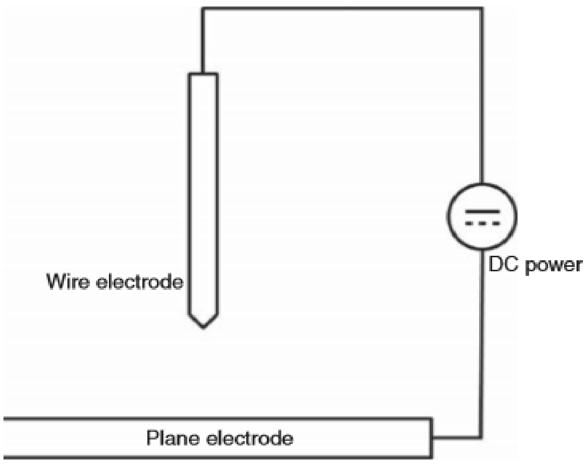


Fig. 4: Corona Discharge (Schematic Representation).

Plasma needle

Stoffels et al. in 2002 developed miniature atmospheric plasma needle and in 2004 new version was created. The new version plasma needle consists of 0.3 mm diameter metal stand with a sharpened tip perspex tube.[3] Due to high thermal conductivity helium is most frequently used. Microplasma is generated by plasma needle which can be used to deactivate E.coli.

Fig 5: Plasma Needle.

Plasma pencil

Laroussi et al. developed plasma pencil. It consists two electrodes of same diameter and the diameter is 2.5 mm. High voltage submicro sceond pulses are applied between electrodes to create plasma, while gas is injected through electrode hole.[3,5] When discharge is created plasma pulme is launched through the hole of outer electrode. Due to low temperature (290 K) plasma pulme (length up to 5 cm) can be touched safely. Plasma pencil has been used for P. gingivalis, E. coli, leukemia treatment.

Fig. 6: Plasma Pencil.

Mechanism of Action

The mechanism of action of plasma is based on release of free radicals and reactive species (e.g., reactive oxygen and nitrogen species, i.e., ROS and RNS), Metastables and UV Light.

These radicals control the cell redox signaling pathway.[5] Electrons get accelerated by the presence of an electromagnetic field at a very faster rate than heavy ions. These accelerated electrons are comparatively less effective in transferring energy to heat their surrounding environment than heavy ions. Accelerated electrons results into ionization of particles, radiation, and creation of reactive species.[6] Common gas sources used for the production of plasma are argon, hydrogen, oxygen, or nitrogen. and can be used for sterilization and wound healing and apoptosis of cancer cells, but their high concentration can have adverse effects on the cells. It has been found that non-thermal plasma can produce significant amounts of ozone. This generated ozone in aqueous media further generates biologically active ROS and RNS.

Applications of Plasma In Dentistry

Dental applications have emerged because a new version of plasma technology, the "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 oxygen species, reactive nitrogen species, metastables in low gas temperature along with charged particles, radiation.[7] The complex components from non-thermal plasmas achieve multi-functional treatment in oral cavity.

The dental applications of physical plasma can be sub divided into two principal approaches:

A) Treatment of surfaces, materials or devices to enhance specific qualities for subsequent special applications including disinfection. Surface treatments made use of NTAPP in the form of chairside applications.

B) Direct Applications on or in the human body for therapeutic purposes. All the studies regarding direct applications used Non thermal atmospheric plasma even though the individual settings varied.

Surface treatments	**Direct applications**
Surface modification of Implants	Microbicidal activities
Plasma Cleaning and sterilization of Dental Instruments	Treatment of Dental caries
Enhancing adhesive qualities	Root canal disinfection
	Tooth Bleaching

1) **SURFACE TREATMENTS OF PLASMA**

Modification of the implant surface to improve osseointegration: The modification of implant surface is being carried out using plasma technology to improve osseointegration.[7]

Since the implant surface is the first part to interact with the host attempts are being made to hasten the early host-to-implant response The rationale for its modification focuses upon implant interaction with biofluids, which positively alters the cascade of events leading to bone healing and intimate interaction with the surface. Plasma treatment is capable of improving cell adhesion by changing surface roughness and wettability. A chairside operating NTAPP immediately prior to implant placement was also reported, which stated that plasma treatment reduced the contact angle and supported the spread of osteoblastic cells. One of the advantages of plasma treatment is that it leaves no residues after treatment.

Modification of titanium surface: Plasma spray coating is one coating process where melted materials are sprayed onto the surface of titanium. Materials to be deposited are introduced into a plasma torch, melted and are then propelled towards a substrate.[5] Coating of titanium through the plasma-enhanced chemical vapor deposition (PECVD). PECVD is a process that deposits a thin film from plasma-activated gases onto substrates. Hayakawa et al. coated pure titanium disks with hexamethyldisiloxane (HMDSO) using a commercially available plasma deposition system. HMDSO is an organosilicon monomer, which has high deposition rates and is easy and safe to handle. HMDSO coating made the surface of titanium more hydrophobic. More fibronectin, a well-known cell-adhesive protein, was absorbed onto HMDOS-coated titanium than pure titanium. It was concluded that plasma polymerization would become a useful technique for the surface modification of titanium and HMDSO-coated titanium had the potential for application as a dental implant.

Fibre reinforced composite post: Fiber-reinforced composite (FRC) posts are widely used with the demand for esthetic restorations.[7] To achieve ‘monoblock’ condition, reliable adhesion between FRC posts and resin composites is essential. However, the highly cured and cross-linked matrix of FRC posts disturbs effective adhesion to resin cements or resin composite core materials. There are studies of plasma application to enhance the adhesion between FRC posts and resin composites. The surface treatment of fibre posts with plasma can improve the hydrophilicity of epoxy polymers due to oxygen containing functional groups which improve the humectation that is wetting of post surface along with changing the chemical composition of the surface.[8] Plasma treatment can have various effects on the surfaces of polymers, such as removal of organic contaminants and weak boundary layers by cleaning and ablation; degradation of the polymer chain;formation of radicals on the surfaces; creation of a thin crosslinking layer; and formation of chemical groups on the stabilized surfaces.[8] These effects result in acid-base interactions and covalent linkages. Argon plasma can induce free radicals on the surface of polymers through ion bombardment. Amine and imine carbon species induced by N2 plasma may contribute to adhesion. A study by Usama M et al. (2016) and A. A Younes(2015) suggests plasma treatment of fibre posts for 5-6 minutes.[8,9] Piriya Yavirach et al. (2009) conducted a study where he treated fibre posts with for 10 mins.[10]

Plasma Cleaning: The plethora of plasma components such as, reactive oxygen species (ROS), electromagnetic fields, and ions and electrons is related to the mechanism of plasma sterilization. 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. Plasma cleaning is advantageous when compared to the conventional methods of cleaning such as the use of solvents or aggressive chemicals, as the former leaves no residue.[5] The only gaseous waste generated consists of Carbon dioxide, Water and Nitrogen. Its advantages include: lack of toxic residue, reduced turnover time, and applicability for sterilization of heat- and moisture-sensitive instruments. In one experiment, using diamond burs and silicone impression materials, the colony – forming unit was significantly reduced for both E. coli and B. subtilis after treatment with atmospheric pressure nonthermal air plasma. Dental treatment can frequently induce cross-contamination between dental patients and dentists through instruments and materials as well as between impression materials and dental technicians.[7] Contaminated endodontic files exposed for a short period to low-pressure oxygen–argon plasma showed a reduction in the absolute amount of proteinaceous materials in a study as the proteins are also susceptible to the attack of free radicals like hydroxyl ions when exposed to plasma.

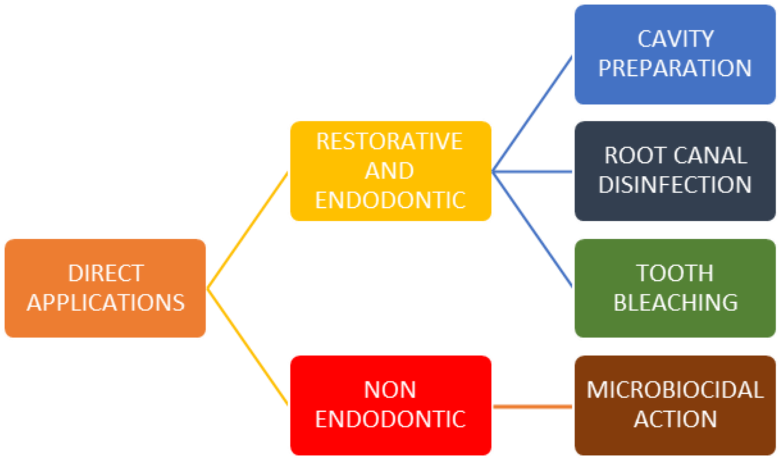
Enhancing Adhesive Qualities: Adhesion is the main concern of dentistry, intra-orally and in the laboratory. It is a critical factor in improving the performance of dental composites. Optimal adhesion could be achieved when the adhesive material is spread impulsively across the entire adherend surface. Optimal wettability of the substrate is achieved with reference to that adhesive.[5] The plasma generates reactive species that arrive on the surface of the composite resulting in both microstructural and surface chemistry modifications that improve adhesive bonding. these highly reactive plasma species react with, clean, and etched surface materials, bond to various substrates, or combine to form a thin layer of plasma coating, and consequently alter the surface characteristics. Atmospheric cold plasma brush (ACPB) treatment can enhance adhesive qualities.[7] Ritts *et al*. assessed the effect of NTP(Non Thermal Plasma) brush on composite restoration. It was found that NTP can alter the surface characteristics of dentin, which results into increased bonding between dentin and adhesive restorations. Chen et. al reported that a super-hydrophilic surface could be easily obtained by plasma brush treatment without affecting the bulk properties regardless of the original hydrophilicity. Yavirach *et al*. in his study found that plasma treatment of fiber-reinforced composite and resin composite have more tensile shear bond than traditional core build up. Plasma has been used to modify the surface of polymers and to deposit an inert protective layer. The plasma processes can increase wettability, biocompatibility and durability without influencing bulk material properties. A study by Dong X et al in 2014 revealed that plasma treatment of the peripheral dentin surface resulted in an increase in the interfacial bonding strength by modifying dentin surfaces and improving monomer penetration into the exposed collagen fibrils and dentin tubules. Plasma treatment could loose collagen helix structure and help monomer penetrate into dentin tubules and collagen networks, form thicker hybrid layer and longer resin tags, which is beneficial to enhancing adhesive-dentin interfacial bonding.[11] By delivering reactive species, including ions, radicals, and UV photons, Non thermal Plasma have exhibited various biological and chemical effects critical to dental bonding. For adhesion enhancement in dental ceramic bonding, atmospheric pressure plasma treatment has been suggested. It enhances adhesion by producing carboxyl groups on the ceramic surface and improves the surface hydrophilicity.

Enhancing polymerization: Plasma induce polymerization. Polymers synthesized by plasma exposure demonstrated high cross-linking and high degrees of polymerization. For composite resin, plasma arc curing units have been used because of their short curing time in comparison to conventional units.[2,3] The non-thermal plasma brush was reported to be effective in the polymerization of self-etch adhesives with no negative effects of water on the degree of conversion of plasma cured samples.

Plasma treatment has been introduced as an alternative or additional procedure, even in the bonding of ceramic restorations.[5] It enhances adhesion by producing carboxyl groups on the ceramic surface and improves the surface hydrophilicity as a result.

The nonreactive surface of zirconia, sometimes described as "ceramic steel", presents a consistent issue of poor adhesion strength to other substrates. In addition, zirconia itself is known to be hydrophobic and possesses very low surface concentrations of OH groups. For this more complicated bonding, several other methods have been proposed.[7] Plasma treatment was also tested and the results showed that a significant increase in the microtensile bond strength to zirconia surfaces was observed when non-thermal plasma was applied alone or in combination with resin. According to the XPS results, an increase of elemental O and a decrease of elemental C was detected on the zirconia surface after non-thermal plasma application. One report demonstrated that the high polarity was obtained on zirconia and titanium surface after NTAPP application.

Direct Applications



Microbiocidal Action: Cold plasma is known to have anti bacterial effects. Cold plasmas are of particular interest, as heat damage to dental pulp must be prevented. Biofilms formed over the tooth surface lead to dental caries, gingival and periodontal diseases, and oral mucositis.[5] These biofilms can also affect dental implant by causing peri-mucositis and peri-implantitis. NTP has the ability to destroy biofilm matrix without causing any damage to the oral tissue. Koban *et al*. in his *in-vitro* study found that NTP is more efficient in killing of bacteria present in the dental biofilm than chlorhexidine.[7] The bacterial cell membrane is made up of lipid bilayer, important components of the membrane are the unsaturated fatty acids and the proteins, both are involved in transportation processes across the membrane. The unsaturated fatty acids are susceptible to attacks of Hydroxyl ions. Hydroxyl radicals generated by plasma along with other free radicals destroy membrane lipids and thereby deactivate the bacteria.[1,2] The same is true for the proteins as they are also susceptible to the attack of radicals when exposed to plasma. NTP is also effective in the decontamination of biofilms present either on root canals or on dental slices.

Cavity Preparation: Cold plasma has great potential for use in dentistry as it is vibration-free, leading to lesser pain perception by the patient. It is helpful in dealing with patients suffering from anxiety and fear of the drill use for cavity preparation prior to the restoration of teeth and removal of necrotic, infected, and non-remineralizable tissues. Plasma can treat and sterilize irregular surfaces by making them suitable for decontaminating dental cavities without drilling. Although, plasma itself is superficial, the active plasma species production can easily reach inside 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 by causing cell leakage due to the damage of the lipopolysaccharides in the outer cell membrane and the thin peptidoglycan layers of the cell wall of this Gram-negative bacteria along with degradation of the bacterial DNA and destruction of the capability of the microorganism's reproduction.[12] A plasma needle is an efficient source of various radicals, which helps in bacterial decontamination. Because it operates at room temperature, it does not cause bulk destruction of the tissue. The temperature increase in the pulpal chamber is 2.3 degree Celsius during the plasma treatment of the enamel surface. Short-lived chemical species in the gas phase produced by the plasma needle can interact on a tooth's surface and can dissolve into a liquid. Dissimilar to the liquid rinses with bactericidal ingredients that stay in the mouth after the procedure, the plasma needle produces bactericidal agents locally, which can reach the inside of the cavity and fissure spaces.[12] A low-temperature atmospheric argon plasma brush introduced by Yang et al. was found to be very effective in deactivating Streptococcus mutans and Lactobacillus acidophilus. The authors concluded that about 100% bacterial elimination was achieved within 15 s for Streptococcus mutans and in 5 min for Lactobacillus acidophilus. In comparison to lasers, plasmas can access small irregular cavities and fissure spaces.

Root Canal Disinfection

The Tooth root canal system has complicated structures, such as isthmuses, ramifications, deltas, irregularities, and in particular dentinal tubules. It has been reported that bacteria can enter dentinal tubules as deep as 500–1000µm. Eliminating the residual micro-organisms especially within the biofilm is a challenging task and clinical investigations showed that there are around 10% of treatment failures when conventional disinfections were performed. Since persistent endodontic infections are frequently caused by Enterococcus faecalis methods have been undertaken to eliminate this species.[13] Jiang etal. Developed a plasma dental probe and applied the device to extracted teeth for root canal disinfection. NTP containing He/O_2(20%) gas have shown rotational and vibrational temperature of approximately 300 K and 2700 K, respectively. At this temperature, approximately 10 mA of current discharge occurs. Plasma produced at this level can completely kill Enterococcus faecalis which is responsible for failure of root canal treatment. NTP as a gas phase has a capability of reaching deep into the complex canal.[13] Therefore, there is a unique advantage of direct contact with bacteria when using NTP, which is compulsory but impossible with conventional methods. The effective inactivation of E. faecalis has been attributed to several mechanisms, such as excited species, charged particles, and ultraviolet radiations.[14] Among these, several studies suggested that the reactive oxygen species plays the most crucial roles in bacterial inactivation. Lu et al. developed a plasma jet device, named 'Model RC-1', using a medical syringe and a needle. The device was powered by an 8 kV, 500 ns pulsed direct current at a pulse frequency of 10 kHz. The gas mixture of 80% He and 20% O2 was injected into the syringe at a flow rate of 0.4 slm. The needle served as an electrode and had an inner diameter of ~200 m. Therefore, the needle could be inserted into the root canal and generate a very narrow plasma plume.

Tooth Bleaching

Tooth bleaching has become a popular esthetic service in dentistry. Hydrogen peroxide (H_2O_2) is a widely used bleaching material that is effective and safe. NTP have also been used in teeth bleaching. Lee *et al*. in his study used NTP for teeth bleaching and demonstrated that this effect is due to the release of hydroxyl radicals and removal of surface proteins. He developed an atmospheric pressure plasma jet and applied the device to enhance the effect of hydrogen peroxide on tooth bleaching.[15] The device consisted of a Teflon tube and an outer electrode that was connected to AC power with a peak voltage of 10 kV and a frequency of 20 kHz. Helium was used as the working gas at a flow rate of 2 slm. The authors found that NTP in combination with hydrogen peroxide were able to remove stains from extracted teeth.[16] Direct current plasma jet along with hydrogen peroxide can also be used for tooth whitening. Low frequency plasma source along with hydrogen peroxide can be used to remove intrinsic stain. The plasma treatment with Hydrogen peroxide solution is more effective than the H_2O_2 solution alone in intra-coronal bleaching.[15] The temperature of the tooth was maintained at 37 degree C during the plasma treatment. NTP was the most effective in tooth bleaching without causing any damage to the tooth than carbamide peroxide alone and a combination of carabamide peroxide and diode laser.

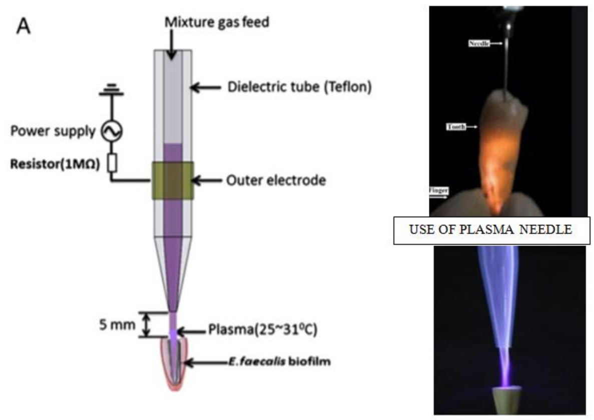


Fig 7: Schematic diagram of mechanism of action of plasma needle- distance between tip of nozzle and tooth sample should be greater than 5mm.

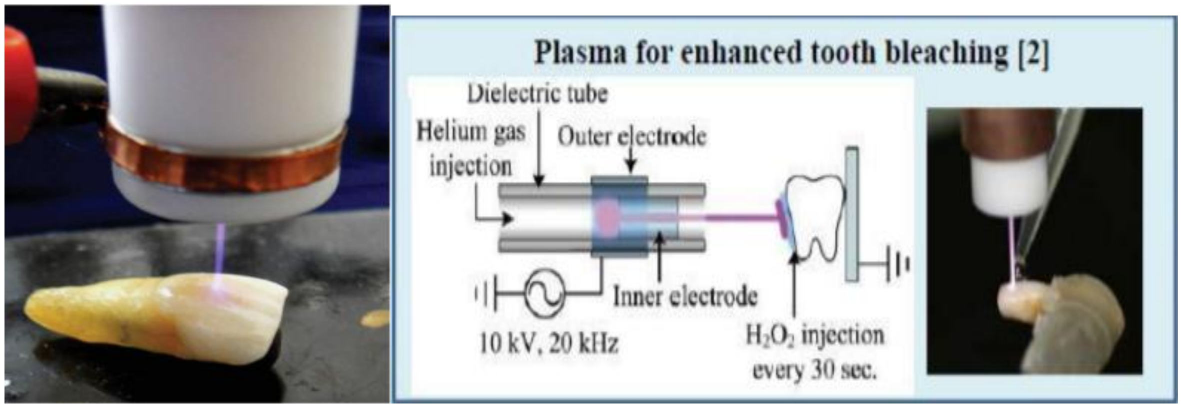


Fig 8: Plasma for Tooth Bleaching.

Dual arch bleaching done by Plasma arc Sapphire lamp in 30-60 minutes.

CLINICAL STEPS OF PLASMA BLEACHING

(**Courtesy**: Viet Giao Dental Clinic, Vietnam)

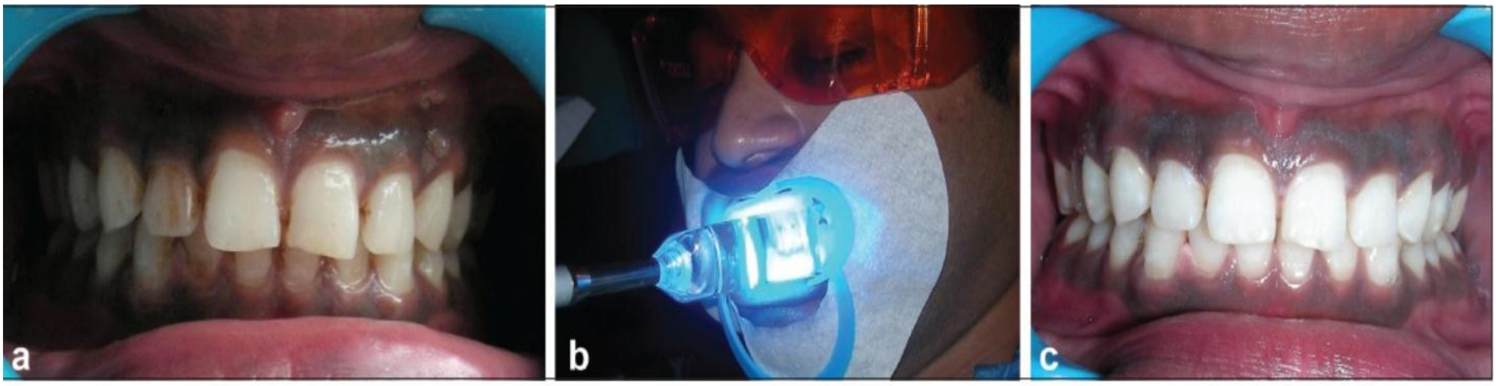
Examination before bleaching	Comparison of tooth colour.

Application of a layer of Vaseline	Layer of gingival barrier to cover gingiva and then Forever White Teeth Whitening Pen 36% Carbamide Peroxide Gel

Brushing gently over the teeth to cover the entire surface	Application of plasma arc light for 5mins

Medication is repeated thrice	Finally after rinsing the desired shade Is obtained.

CLINICAL CASE-Deepika Thosre, Sanjyot Mulay



a.Pre operative; yellowish brown discolouration of teeth	b. Application of bleaching agent and activating using plasma arc light for 10-15 mins, 6-7mm away from teeth. 35% H_2O_2 used for 4 cycles.	c. Teeth were then polished using diamond polishing paste.

LIMITATIONS

CAP also has some limitations as this is a new technology, safety of the equipment has to be taken care of.

1. Portability of instrument for dental use is also one factor.
2. This technique is highly sensitive
3. It does not work well in cases where amalgam restoration is present in the oral cavity.
4. Spores are difficult to inactivate due to the limited penetration depth of cold plasma.
5. Cost of the equipment, marketing, maintenance and availability are also some of the issues at present.

This is a beginning and still some research is needed for this technology to be used in a cost effective, efficient and predictable manner in clinical settings.

CONCLUSION

Based on the above evidence, we can say that CAP has a bright future in dentistry due to its anti-microbial properties and its cell death properties on cells. It can be used in almost all the branches of dentistry. However, more studies need to be performed regarding the mechanism. Plasma dental treatments are basically painless, drill-less, patient-friendly especially in children, under-served communities, where education and familiarity with the dentist's chair are limited. Although plasma technology isn't an end-all to all the techniques we perform, it could well become a valuable tool in dentistry in near future.

REFERENCES

1. Nair RS, Babu B, Mushtaq E. Cold Atmospheric Plasma in Dentistry. J Oper Dent Endod, 2016; 1(2): 82-96.
2. Ranjan R, Krishnamraju P. V, Shankar T, Gowd S. Nonthermal Plasma in Dentistry: An Update. J Int Soc Prev Community Dent., 2017; 7(3): 71–75.
3. Jairaj A, Shilpa PH. Plasma: From Distant Stars to Dental Chairs. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 2015; 6(5): 1129-37.
4. Sinha D J. Cold Plasma: A new realm in Endodontic Disinfection. International Journal of Current Research, 2015; 7(9): 20597-602.
5. Nagy Abdulsamee. Expanded Tentacles of Cold Plasma Energy in Dentistry – Review. EC Dental Science, 2017; 11(6): 223-239.
6. Arora V, Nikhil V1, Suri NK and Arora P. Cold Atmospheric Plasma (CAP) In Dentistry. Dentistry, 2014; 4(1): 189.
7. Akash Azad. Dental applications of cold atmospheric plasma. International Journal of Contemporary Medical Research, 2017; 4(6): 1304-5.
8. A.A. Younes a, , M.S. Kamel a , M.A. Shakal a , A.E. Fahmy. The effect of various fiber reinforced composite post surface treatments on its bond strength to root canal dentin. Tanta Dental Journal, 2015; 12(1): S15-S21.
9. Karim U A, Alhadainy H A. The effect of plasma surface treatment on push out bond strength of fibre reinforced posts to root canal dentin. Tanta Dental Journal, 2016; 13: 127-32.
10. Yavirach, Piriya et al. Effects of plasma treatment on the shear bond strength between fiber-reinforced composite posts and resin composite for core build-up. Dental materials journal, 2009; 28(6): 686-92.
11. Dong X, Chen M, Wang Y, Yu Q. A Mechanistic study of Plasma Treatment Effects on Demineralized Dentin Surfaces for Improved Adhesive/Dentin Interface Bonding. Clin Plasma Med., 2014; 2(1): 11-16.
12. Theinkom F, Singer L, Cieplik F, Cantzler S, Weilemann H, Cantzler M. Antibacterial efficacy of cold atmospheric plasma against Enterococcus faecalis planktonic cultures and biofilms in vitro. PLOS ONE, 2019; 14(11): e0223925.

13. U. Kamath, Rajasekhara. S, Nazar N, Abdul Sathar M. Cold Atmospheric Plasma; Break Through in Dentistry-A Review. Indian Journal Of Research, 2016; 5(7): 18-21.
14. Sarkar A, Pal D, Sarkar S. Cold atmospheric plasma-future of dentistry. IOSR Journal of Dental and Medical Sciences, 2018; 17(8): 15-20.
15. Aishwariya P. S, Mohamed Jubair .M. Plasma: Pursuit of Dentistry. International Journal of Science and Research, 2017; 6(6): 1789-97.
16. Kumar Ch S, Sarada P, Reddy Ch S, Reddy M S, Dsv N. Plasma torch toothbrush a new insight in fear free dentisry. J Clin Diagn Res., 2014; 8(6): ZE07-10.
17. Sladek REJ, Stoffels E, Walraven R, Tielbeek PJA, Koolhoven RA. Plasma treatment of dental cavities: a feasibility study. IEEE Trans Plasma Sci., 2004; 32: 1540–3.