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REVIEW ARTICLE

PLASMA MATTER – A PROMISING REALM IN DENTISTRY

Rohini Dua[1], Annupriya Sikri[2], Vishu Midha[3], Vasu Midha[3]

[1]Professor and head, [2]Assistant professor, [3]PG Student, Department of Pedodontics and Preventive Dentistry, National Dental College and Hospital, Dera Bassi, Mohali, Punjab, India

ABSTRACT:
Plasma in dentistry is an emerging field in today's world attributed to its increasing scope and benefits. When People normally think about matter, obviously they think of solid, liquid and gases. Nevertheless there is fourth state of matter called plasma that's actually the most unusual and abundant form of matter. Non-thermal plasmas have shown great potential as noble techniques to dental applications due to safety and multi-functional effects achieved by the abundant plasma components. This review article will exhibit the essential information about plasma that is plasma products, mode of production, its applications and pros & cons in the dental field.
Key words: Cold atmospheric plasma, Dentistry, Plasma

Corresponding author: Dr. Rohini Dua, Professor and head, Department of Pedodontics and Preventive Dentistry, National Dental College and Hospital, Dera Bassi, Mohali, Punjab, India

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INTRODUCTION

PLASMA is considered as fourth state of matter. The other three states of matter are solid, liquid and gas. It is a partially ionized gas with ions, electrons, and uncharged particles such as atoms, molecules, and radicals.

There are two types of plasma: thermal and non-thermal or cold atmospheric plasma. Thermal plasma has electrons and heavy particles (neutrals and ions) at the same temperature. Cold Atmospheric Plasma (CAP) is said to be non-thermal because it has electrons at a hotter temperature than the heavy particles that are at room temperature. CAP is a specific type of plasma that is less than 104°F at the point of application.[2]

The oral cavity is the entrance to the digestive system. Teeth constitute approximately 20% of the surface area of the oral cavity and serve several functions such as mastication, proper speech and also its role in aesthetics.[3]Bacteria cause oral infections, including dental caries, periodontal disease, and intraoral disease that may result in toothdestruction.[4]Even though teeth brushing, fluoride uptake, antibiotics, and vaccines have been used as treatment modalities for oral disease, these conventional treatments have their own limitations.[5] For example, heat kills bacteria, but the application of this method will be dangerous for living tissues. Sterilizing agents or antibiotics are used to treat human tissues which are pathogens infected, but this method may lead to pain and antibiotic resistance. Recently, non-thermal atmospheric plasmas have proved itself to be highly efficient at killing bacteria in an inexpensive manner; therefore, the use of such plasmas could overcome the problems which are associated with use of heat and antibiotics.[6,7]

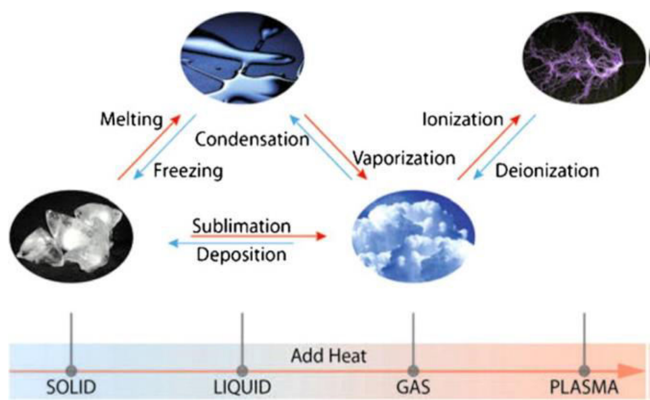

Figure 1: Various stages of transformation of the plasma matter

HISTORY

The British physicist Sir William Crookes identified the fourth state of matter in 1879, but it was not called "plasma" until Irving Langmuir, an American chemist, applied the name in 1929. In the late 1850s, the Siemens Company used plasma discharge to generate ozone, which acted as an agent to remove contaminants and toxins from water. Nevertheless, for the next 100 years, little research was conducted exploring the relationship between plasma and biological cells. From the 1960s to 1980s, plasmas were mainly utilized as a secondary agent to indicate biological sterilization, yet diminutive cause and effect knowledge was advanced. It was not until the mid- 1990s that scientists made considerable progress in cold plasma technology. As the news of plasma science spread, visionary researchers took notice and began to explore various ways to utilize plasma's unique properties. Plasma science was in its infancy in the 1990s, but by 1997, multidisciplinary teams set out to understand the effects that plasmas had on pathogenic and nonpathogenic microorganisms, as well as develop proof of concept studies to demonstrate that plasma could be used as a decontaminant or sterilizing agent.[8]

As the most common form of matter, making up more than 99 percent of the visible universe, 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. Unlike ordinary matter, plasmas can exist in a wide range of temperatures without changing state. The aurora borealis, or northern lights, is ice cool, for instance, while the core of a distant star is white hot. Other well-known plasmas include lightning, neon signs, and fluorescent lights. Outside of a container, plasma resembles gas—the particles don't have a definite shape. But unlike gas, magnetic and electric fields can control plasma and shape it into useful, malleable structures.[9]

MODE OF PRODUCTION

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. Usually, the discharge needed to produce CAP is induced electrically.

Some methods used to produce CAP include: Dielectric Barrier Discharge (DBD), Atmospheric Pressure Plasma Jet (APPJ), Plasma Needle, and Plasma Pencil.[10]

1. **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.[11,12]The dielectric barrier discharge (DBD) consists of two flat metal electrodes that are covered with dielectric material. A carrier gas moves between the two electrodes and is ionized to create plasma. One electrode is a high voltage electrode and the other is a grounded electrode. High voltages are required to produce the discharge needed to create the plasma. Alternative Current (AC) high voltages generally drive DBD"s with frequencies in the kHz range. The power consumption is between 10 and 100W.[13]

FLOATING ELECTRODE DIELECTRIC BARRIER DISCHARGE-it is the modification of DBD, which was developed by Fridmanet al.[14]it consists of two electrodes: an insulated high voltage electrode and an active electrode. The difference between FE-DBD and DBD is that the second electrode is not grounded; it is active meaning that the second electrode can be human skin, a sample, and even an organ. The powered electrode needs to be close to the surface of the second electrode (< 3mm) to create the discharge. It has been used on endothelial cells, melanoma skin cancer, and blood coagulation. It has also been used in living tissue sterilization and in deactivation of Bacillus stratosphericus. (Figure 2)[15].Plasma jets using a DBD system have also been created.[16]

2) **ATMOSPHERIC PRESSURE PLASMA JET (APPJ)**- In 1992,Schutz et al created radiofrequency plasma jet called Atmospheric Pressure Plasma Jet (APPJ). It is the type of plasma jet which is used for bacterial sterilization.[17] The APPJ consists of two coaxial electrodes between which a feed gas (mixtures of helium, oxygen, and other gases) flows at a high rate. The outer electrode is grounded while Radio Frequency (RF) power (50-100W) at 13.56 MHz is applied to the central electrode that creates a discharge. The reactive species produced exits the nozzle at high velocity and arrives to the area that is to be treated. APPJ has been used for the inactivation of several micro-organisms.[18-21]

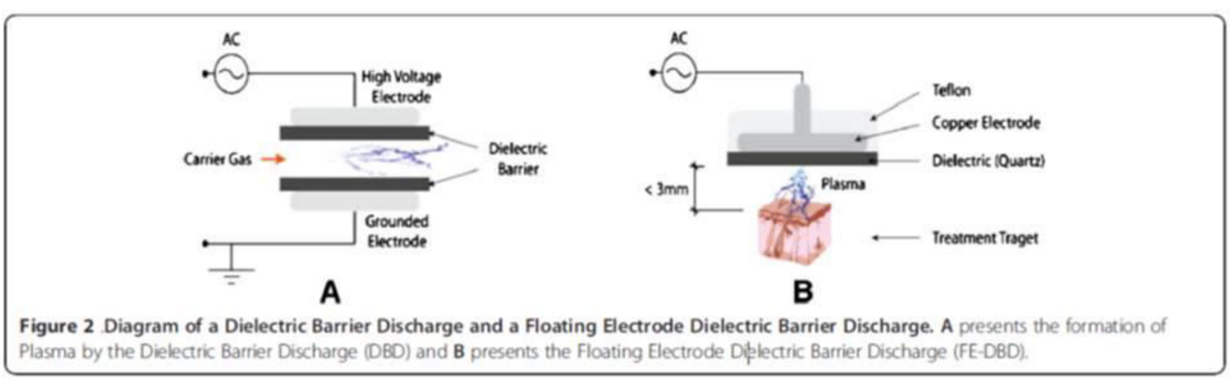

Figure 2: Dielectric barrier discharge and floating electrode dialectric barrier discharge

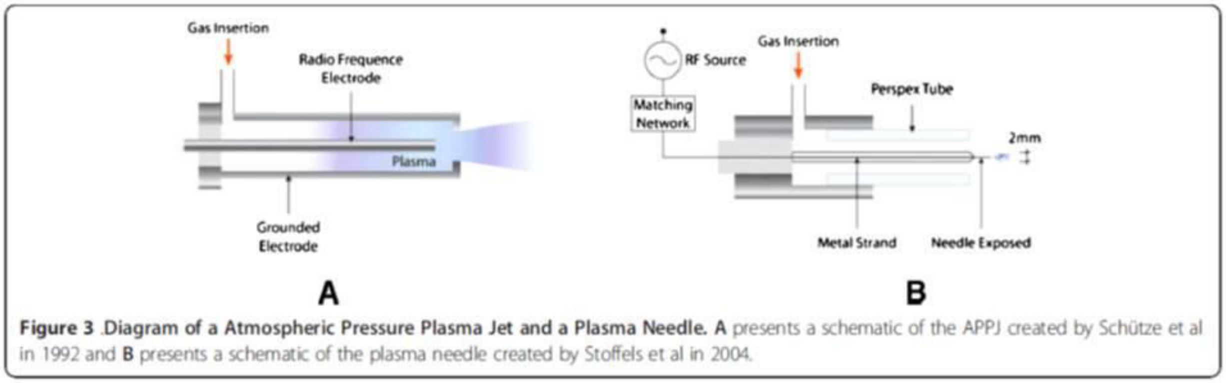

Figure 3: Atmospheric pressure plasma jet and a plasma needle

3) **PLASMA NEEDLE**-In 2002, Stoffels et al. created miniature atmospheric plasma jet that they called plasma needle[22] and created a new version in 2004.[23] In the former version, the needle was enclosed in a box and as a result, the samples had to be placed inside of the box to be treated. In the new version, the plasma needle consists of a 0.3 mm metal strand diameter with a sharpened tip inside of a Perspex tube. The length of the entire needle is 8 cm and 1.5 cm remains uncovered by the Perspex tube. The gas used most frequently is Helium due to its high thermal conductivity. The gas is then mixed with air at the needle tip where a micro discharge is created. Gases other than Helium are also used.[24]The diameter of the plasma glow generated is 2 mm. Micro plasma is created when RF power at 13.05 MHz ranging between 10 mW and several watts is applied to the needle. Its small size enables it to be used to treat small areas where accuracy is required like in dentistry. It has also been used to deactivate E. Coli**. (Figure 3)**[25]

4) **PLASMA PENCIL**- It is a plasma direct current driven plasma jet.Laroussi et al. developed a miniature jet that they called plasma pencil.[26]It consists of a dielectric cylindrical tube of 2.5 cm in diameter where two disk electrodes of the same diameter as the tube are inserted. The two electrodes are separated by a gap (the distance can vary from 0.3 to 1 cm) and consist of a thin copper ring attached to a dielectric disk. To create the plasma, sub-microsecond high voltage pulses are applied between the two electrodes while a gas is injected through the holes of the electrodes. When the discharge is created, a plasma plume is launched through the hole of the outer electrode into the air. Because the plasma plume (up to 5cm in length) remains at low temperature (290K), it can be touched safely. The electrical power is supplied to the electrodes by a high voltage pulse generator. The high voltage is supplied to the pulse generator by a DC voltage supply with variable output. The plasma pencil has been used in the treatment of E. coli, Leukemia cells and P.gingivalis.[27] **(Figure 4)**

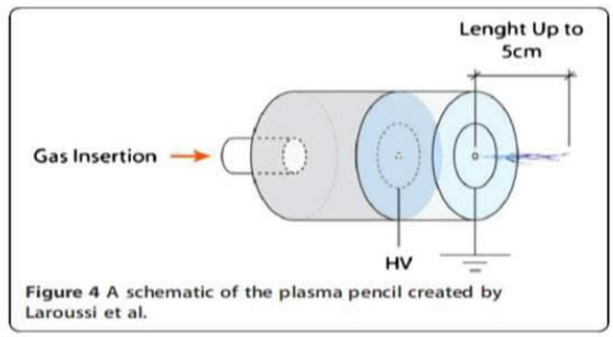

Figure 4: Plasma pencil schematic diagram

APPLICATIONS OF PLASMA IN DENTISTRY

STERLIZATION-the sterilization of instruments is primary concern for both dentists as well as for patients. The sterilization efficacy of plasma devices is influenced by gascomposition, driving frequency, and bacterial strain, but plasma devices kill a higher proportion of bacteria than do conventional non-thermal methods such as UV sterilization.[28,29]The mechanism of plasma sterilization is related to the abundance of plasma components, including reactive oxygen species, ions and electrons, andUV and electromagnetic fields.[30] Moreover, plasma canaffect not only the contacted point but also the area around it. Whittaker et al. has indicated that the use of gas plasma cleaning may be extremely beneficial in reducing the absolute amount of proteinaceous materials that may be transferred between patients when endodontic files are reused.[31] Yang Hong Li et al. stated that plasma sterilization, with the advantage of low temperature, fastness, thoroughness, safety, overcomes the deficiency of the traditional sterilization technology, and may become a novel method for killing microbe.[32] Autoclaves and UV sterilizers are presently used to sterilize dental instruments. To develop a dental sterilizer, Su-Jin Sung et al evaluated which can sterilize most materials, such as metals, rubbers, and plastics, the sterilization effect of an atmospheric pressure non-thermal air plasma device. It was proved that the atmospheric pressure non-thermal 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.[33] [Figure 5]

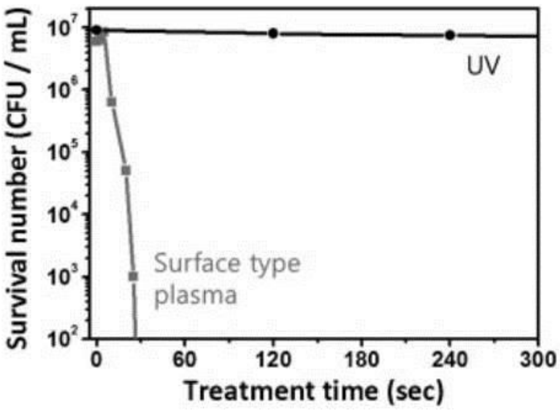

Figure 5: Sterilizing effect of plasma and UV. Surface type plasma device generated atmospheric non-thermal air plasma, while a conventional UV lamp was used for the UV case. Surface type plasma significantly inhibits the proliferation of bacteria, compared with UV.

DENTAL CARIES-Dental caries are tooth decay caused by acid erosion of the tooth enamel.[34]Many different types of bacteria normally live in the oral cavity and build up on the teeth in a sticky film called plaque (figure 6)[35] Dental plaque harbors 200–300 species of microorganisms. The most common cariogenic pathogens are Streptococcus mutans, S. anginosus, S. constellatus, S. gordonii, S. intermedius, S. mitis, S. oralis, S. salivarius, and S. sanguis.[36]These bacteria generate acids on the tooth surface by metabolizing carbohydrates; these acids cause demineralization of the enamel and dentin, and subsequent carious lesions.[37]**[Figure 6]**

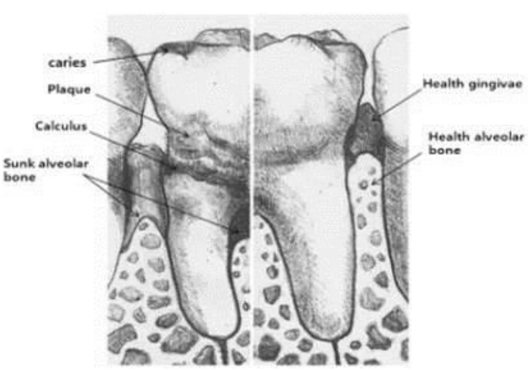

Figure 6: Healthy Tooth (Right); Abnormal Tooth (left)

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*. [38]Goree et al., provided substantial evidence that non thermal atmospheric plasmas killed *Streptococcus mutans*, a gram-positive cariogenic bacterium.[39]Sladek et al., studied the interactions of the plasma with dental tissue using a plasma needle.[40] 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- C. albicans is an opportunistic fungus that causes oral and genital infections in immune-compromised individuals. Oral candidiasis includes Candida-associated denture stomatitis, angular stomatitis, median rhomboid glossitis, and linear gingival erythema. In particular, hyperplasticcandidiasis increases the risk of oral cancer. Koban et al.and Yamazaki et al. reported the high efficiency of C. albicans sterilization using various Plasmas. This result indicates the possibility that stomatitis caused by C. albicans can be cured by plasma jets.[40,41]**(Figure 7)**

Figure 7: Stomatitis caused by C. albican cured by plasma jets

ROOT CANAL DISINFECTION-Treatment of root canal infection is hard. Because it is difficult to penetrate

irregular and narrow spaces, killing the pathogens is difficult; thus, infections frequently recur. Plasma can efficiently kill Enterococcus faecalis, one of the main bacterial species that cause failure of root-canal treatment, within several minutes.[42] 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/O2(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.[43]
(Figure 8)

Figure 8: Root canal disinfection

COMPOSITE RESTORATIONS-
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 demineralize dentin. Interactions between demineralized 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]

Figure 9: Composite restorations enhanced by plasma jets

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.[44]
Ritts et al. investigated a non-thermal atmospheric plasma brush on dental composite restoration. It was observed that atmospheric cold plasma brush (ACPB) treatment could modify the dentin surfaceand increase dentin/adhesive interfacial bonding. [45]
Yavirach et al. studied the effects of plasma treatment on the shear bond strength between fiber reinforced composite posts and resin composite for core buildup And concluded that plasma treatment increased the tensile-shear bond Strength between post and composite.[46]

TOOTH BLEACHING- CAP can also be used to bleach teeth. Lee et al. showed that atmospheric pressure plasma in place of light sources bleached teeth by increasing the production of OH radicals and the removal of surface proteins. [35]
Also, in combination with hydrogen peroxide, this plasma removed stains from extracted teeth stained by either coffee or wine.[47] The tooth bleaching method using an atmospheric pressure jet shows reasonable promise of becoming practical in the future. Tooth whitening can also be achieved using a DC plasma jet and hydrogen peroxide. Intrinsic stains are a serious factor in tooth discoloration. Park etal. suggested intrinsic whitening using a low-frequency plasma source and hydrogen peroxide.[48] (**Figure 10**)

Figure 10: Intrinsic whitening using a low-frequency plasma source and hydrogen peroxide

Nam et al. used a Plasma jet on forty extracted human molar teeth with intact crowns. The forty teeth were randomly divided into fourgroups (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.[49]

laiborne 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, comparedwith 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.[50]

Nam et al. investigated the efficacy of tooth bleaching using non-thermal atmospheric pressure plasma (NAPP) with 15% carbamide peroxide including 5.4% hydrogen peroxide, as compared with conventional light sources. It was observed that the NAPP has a greater capability for effective tooth bleaching than conventional light sources with a low concentration of hydrogen peroxide without causing thermaldamage.[49]

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.[51] **(Figure 11)**

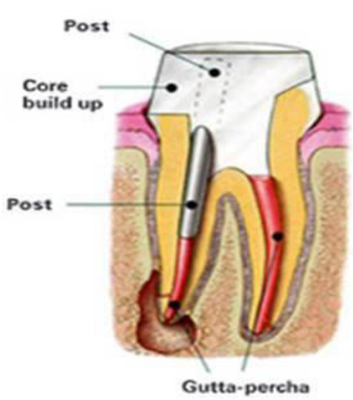

Figure 11: Increased bond strength of Post and core provided by plasma jet

PROS

- Enables the dentist to perform procedures without shots and pain.
- Reduces or avoids the use of routinely practiced painful and destructive drilling .
- Noiseless, painless cavity preparations would be a huge advance.
- SAFE TO USE The flame is cool to touch without any feeling of warmth or touch. It operates at room temperature and does not cause bulk destruction of the tissue, being superior to lasers.

CONS-

CAP also has some limitations, as this is a new technology.

- The technique is highly sensitive.
- Safety of the equipment has to be taken care of.
- Cost of theequipment, marketing, maintenance and availability are also some of the issues at present
- Portability of instrument for dental use is also one factor.

CONCLUSION

Plasma is a gaseous medium that consists of charged particles, radicals, and a strong electric field, and it can penetrate into irregular cavities and fissures. Plasma has many useful advantages in its application to oral tissues.

Furthermore, plasma has the strong advantage in that it kills only pathogens in bacterial plaque on oral tissues, without damaging the normal tissue. 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.[52]

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