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Review Article

Discerning benefits of plasma torch toothbrush & cold atmosphere plasma: An anxiety free approach for paediatric patients

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ABSTRACT:

Recent advancements in dental hygiene technology have introduced transformative tools designed to significantly enhance oral health, with a particular focus on pediatric care. Among these innovations, the plasma torch toothbrush stands out as a revolutionary device with exceptional potential benefits for children. This review explores the plasma torch toothbrush's remarkable advantages, emphasizing its effectiveness in oral care, its pivotal role in reducing dental anxiety among paediatric patients, and its overall impact on user experience. Harnessing the power of plasma technology, the plasma torch toothbrush excels in improving plaque removal, reducing bacterial load, and promoting periodontal health, all while requiring minimal physical effort from children. Its cutting-edge features, including non-invasive plasma treatment and advanced cleaning mechanisms, make brushing not only more effective but also a far more pleasant and stress-free experience for children, who often harbor fears about dental procedures. By synthesizing evidence from clinical studies and user feedback, this review provides a comprehensive assessment of the device's impact on pediatric dental health and user satisfaction. The plasma torch toothbrush marks a significant leap forward in dental technology, offering a novel approach to oral hygiene that overcomes many of the challenges associated with traditional brushing methods. In an arena where dental treatments frequently cause discomfort and anxiety, particularly in young patients, this innovative technology offers a crucial solution by reducing pain and tissue damage, thereby enhancing the overall dental care experience for children.

Keywords: Cold activated plasma, Anxiety free dentistry, Paediatric dentistry, Plasma brush, Plasma jet device

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INTRODUCTION

Solid, liquid, and gas are the three commonly recognized states of matter. Plasma is often considered the fourth state.[1] Plasma is a type of gas that contains particles in the plasma state. It can be described as a gas with free electrons, ions, and various other active atomic or molecular radicals, such as hydroxyl radicals (OH-).[2] Plasma also contains energetic photons, such as ultraviolet light, and intense transient electric fields.[3] Both of these components play a crucial role in bond breaking or the generation of reactive species due to the significant reduced electric field in pulsed discharges.[4] In fact, plasma is the most prevalent form of matter, constituting approximately 99% of the visible universe. From the auroras to the core of stars, plasma exists in various forms throughout the cosmos.[5]In 1879, British physicist Sir William Crookes identified this fourth state of matter, which he termed "plasma." This designation was later validated by Irving Langmuir in 1929.[6]Plasma consists of a mixture of ionized particles resulting from the removal of electrons from atoms and molecules.[7] This state is inherently energetic due to the continuous energy required to maintain ionization. Plasma naturally occurs in various cosmic and terrestrial phenomena, such as fire, the aurora borealis, and nuclear fusion reactions in the sun. It can also be artificially generated, leading to its use in various applications like plasma screens and lighting.[8] Plasma can be classified as thermal or non-thermal based on the temperature differences between electrons, ions, and neutrals. In thermal plasma, electrons and heavy particles are in thermal equilibrium, whereas in non-thermal plasma, electrons are much hotter than the ions and neutrals, which are at room temperature; this form is also known as cold atmospheric plasma (CAP).[9]Non-Thermal Atmospheric Plasma (**Figure 1**), also known as Low-temperature Plasma or Cold Plasma, is utilized for modifying biomaterial surfaces. This type of plasma is characterized by low ionization levels at atmospheric pressure. It is generated by transforming a substance into a gaseous state and ionizing it through energy applications such as heat, electric currents, radiation, or laser light.[10] Common gases used include oxygen, nitrogen, hydrogen, and argon. In materials science, low-temperature plasmas can alter surface properties, including electrochemical charge, oxidation states, and the attachment of chemical groups. This results in adjustable attributes such as hardness, chemical resistance, physical durability, and wettability. Non-thermal atmospheric plasmas are also highly effective in deactivating bacteria, making them a valuable tool in enhancing dental care technologies.Plasma is used in a variety of technologies, including microelectronics and arc welding, as well as in biomedical and dental sciences.[11]

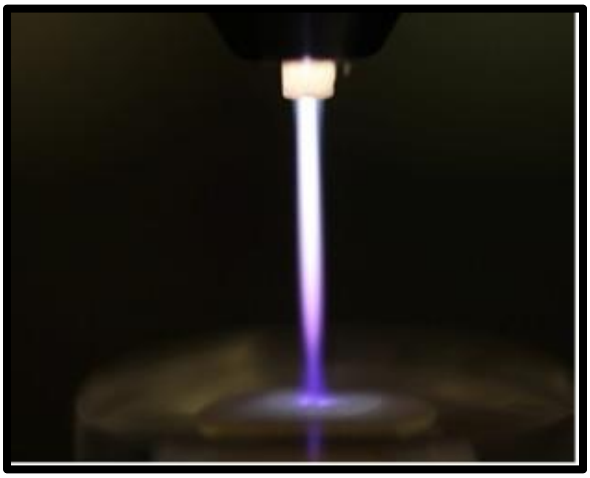

Figure1: Non thermal plasma treatment
Courtesy: Almoammar S, AlShahrani I, Asiry MA, Duarte S, Janal M, Khoo E. Non-thermal plasma treatment to enhance the adhesion between enamel surface and orthodontic bracket. Biomed Mater Eng. 2019; 30(4):439-448.

Overall, the plasma torch toothbrush embodies a promising development in dental technology, potentially offering a more effective and enjoyable method for maintaining oral health.[12]A promising new application is in dentistry, where plasma treatment may offer a novel tissue saving technique for cleaning irregular structures and narrow channels within a diseased tooth. Low-temperature plasma presents a potential alternative to traditional methods, which often have numerous drawbacks.[13] The process of Cold Plasma Generation involves producing cold plasma through various techniques such as radio frequencies, microwave frequencies, and high-voltage alternating current (AC) or direct current (DC). The key components of the system include a medical syringe and a needle that directs the gas flow. The needle serves as an electrode and is connected to a high-voltage (HV) pulsed DC power supply up to 10 kV, with pulse repetition rates up to 10 kHz and pulse durations adjustable from 200 nanoseconds to continuous DC via a 60-kΩ ballast resistor and a 50-pF capacitor.[14]These components control the discharge current and voltage applied to the needle. The resistor and capacitor in series ensure that the discharge current remains within a safe range; preventing minor electric shocks. The syringe has a diameter of about 6 mm, with a nozzle diameter of approximately 0.7 mm. The needle features an internal diameter of around 200 μm and a length of 3 cm.[15] Common gases used include helium, argon, or their mixtures with oxygen. The flow rate of the gas is regulated by a mass-flow controller.[16]Introducing a gas mixture like He/O2 (20%) into the syringe at a flow rate of 0.4 L/min and applying a high-voltage pulsed DC voltage to the needle results in the formation of consistent plasma in front of the needle. This plasma can be touched directly without causing heat or electric shock, making the device safe for uses such as root-canal disinfection.[17]Plasma medicine leverages CAP to produce specific reactive species that target biological surfaces, including tissues and cells.[18] CAP has been effectively employed across various domains, including the sterilization of medical equipment, treatment of implants, microbial disinfection, and blood coagulation.[19]Its advantages—such as scalability, portability, and efficiency in disinfecting confined spaces—make it a versatile tool in both medical and industrial settings.[20] Currently, numerous CAP-based devices are in use for treating tissues and cells. CAP is also employed for rapid sterilization, and there are emerging research opportunities for drug delivery through tissues and biofilms (**Figure 2**).[21]

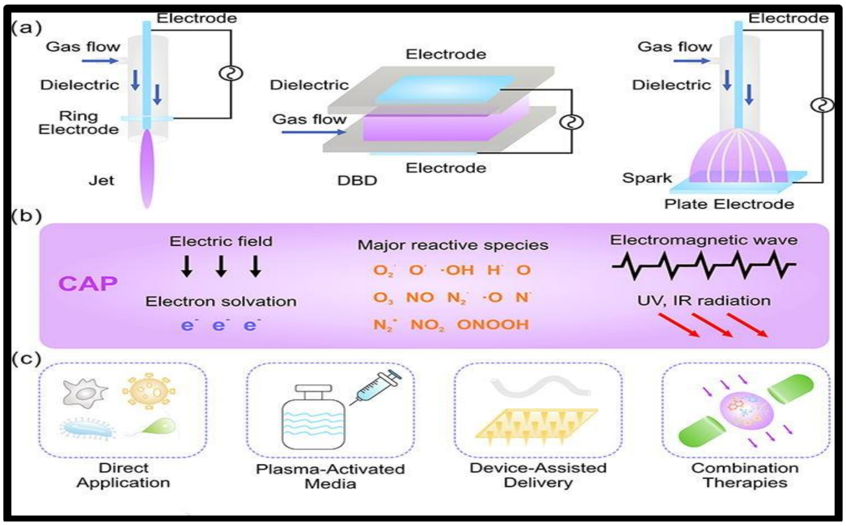

Figure 2: CAP delivery for biomedical applications
Courtesy: Chen Z, Chen G, Obenchain R, Zhang R, Bai F, Fang T, Wang H, Lu Y, Wirz RE, Gu Z. Cold atmospheric plasma delivery for biomedical applications. Materials Today. 2022; 54:153–188.

The outcomes of various studies could lead to the development of plasma-based drug delivery systems.[22]However, this depends on factors like the conceptual design of plasma sources, where chemical reactivity can be managed, the physical application of plasma, and, importantly, both in vivo and in vitro testing.[23]CAP is generated through various methods such as microwave frequencies, radiofrequency (RF), and DC/AC. Being non-equilibrium plasmas, CAPs consist of reactive species like electrons and ions, as well as excited species, all of which hold substantial potential for applications in plasma-based medicine and drug delivery.[24] Plasma medicine is an evolving field fundamentally rooted in plasma physics, which dictates the physical and chemical properties of CAP.[25] The rapid advancements in CAP techniques are attributed to the interdisciplinary nature of the research, integrating physics, chemistry, microbiology, and engineering for the characterization, analysis, and application of CAP technology.[26] It is currently employed in numerous industrial applications, including engineering processes. While several biomedical applications exist, understanding CAP's impact on biofilms—a complex aggregation of microorganisms shielded by a matrix that enhances resistance to external stresses—remains underexplored.[27] Conventional antimicrobial treatments often fail to penetrate biofilms effectively, inhibiting disease eradication, and have issues such as systemic toxicity and bacterial resistance.[28]In contrast, CAP has shown effectiveness against bacteria without inducing resistance, positioning it as a powerful tool for in vivo treatments.[29]Although CAP typically operates near room temperature, it contains highly reactive gas species suitable for a range of biomedical applications.[30] The high-energy electrons in CAP collide with working gases (He/Ar/N2/O2), resulting in higher ionization and dissociation levels, while neutrals and ions remain at lower temperatures, thus avoiding thermal damage. This property allows CAP to be applied to tissues, cells, biological matter, and heat-sensitive materials.[31] Recently, many CAP (**Figure 3**) devices have been designed and developed for various research applications, classified broadly into indirect and direct discharge types.[32]

Figure 3: Plasma torch toothbrush

The diversity in CAP devices used across different research groups complicates direct comparisons. To address this, standardized methods are essential for evaluating the effectiveness and safety of CAP devices.[33] Regulatory bodies such as the European Committee for Standardization, German Institute of Standardization, and International Organization for Standardization oversee CAP device standards. Some CAP devices have already received approval from the United States Food and Drug Administration (FDA) for clinical use.[34]CAP applications have garnered significant attention from the medical research community. Notable biomedical applications include treating viral infections e.g., herpes simplex, wound care, skin diseases, implants surface treatment, and biofilm management.[35]Modeling, simulation, and experimental research are essential for comprehensively understanding the chemical and physical mechanisms underlying atmospheric pressure plasmas.[36] Critical parameters such as seed electrons, photoionization effects, and the influence of electric fields can be investigated using advanced imaging techniques with micrometer resolution and nanosecond time resolution. Detailed analysis of CAP components—such as Reactive Oxygen Species (ROS) (**Figure 4**), Reactive Nitrogen Species (RNS) (**Figure 5**), electric fields, and Ultraviolet (UV) radiation (**Figure 6**) requires an in-depth study of their generation mechanisms and interactions.[37]

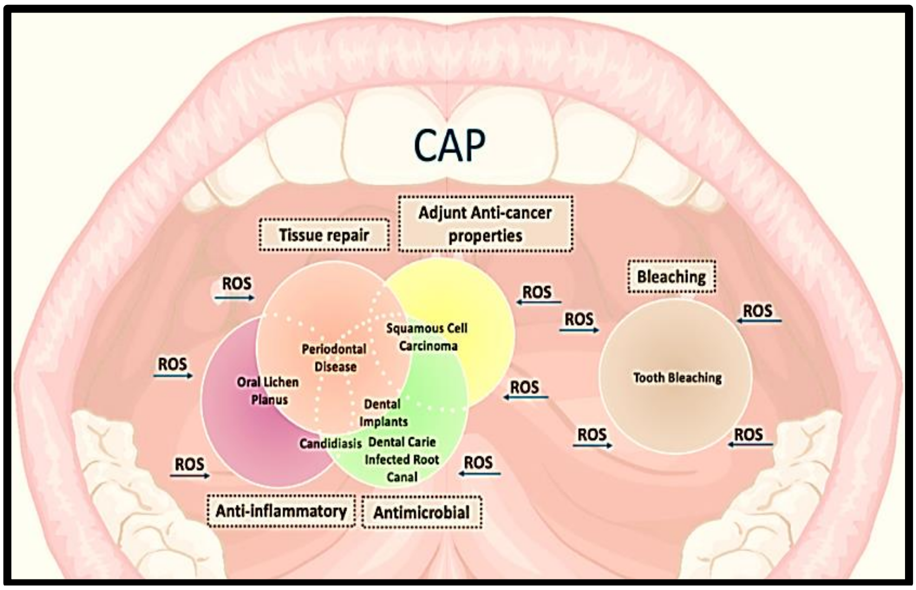

Figure 4: CAP & its interaction with reactive species
Courtesy: Koga-Ito CY, Kostov KG, Miranda FS, Milhan NVM, Azevedo Neto NF, Nascimento F, Pessoa RS. Cold Atmospheric Plasma as a Therapeutic Tool in Medicine and Dentistry. Plasma Chemistry and Plasma Processing. 2024; 44:1393–1429.

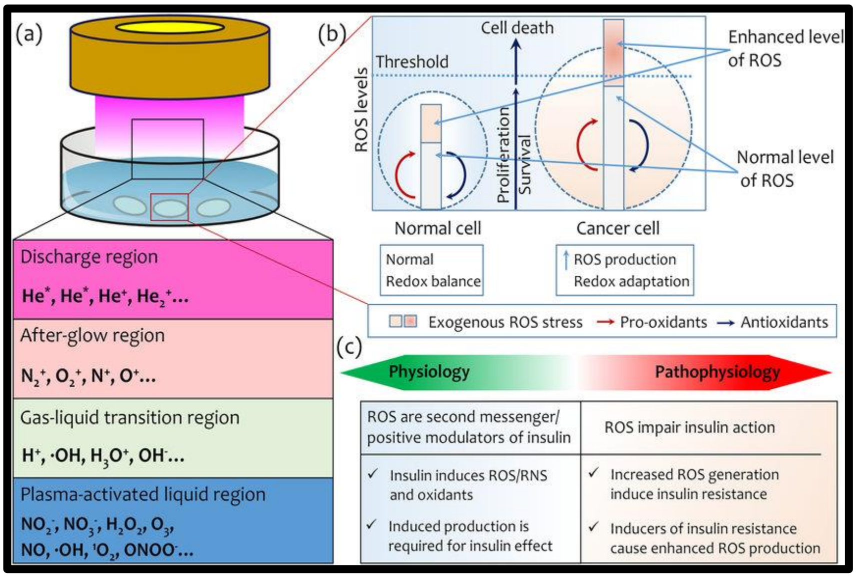

Figure 5: Antioxidant action of CAP
Courtesy: Li HP, Zhang XF, Zhu XM, Zheng M. Translational plasma stomatology: Applications of cold atmospheric plasmas in dentistry and their extension. High Voltage. 2017; 2(3):153-161.

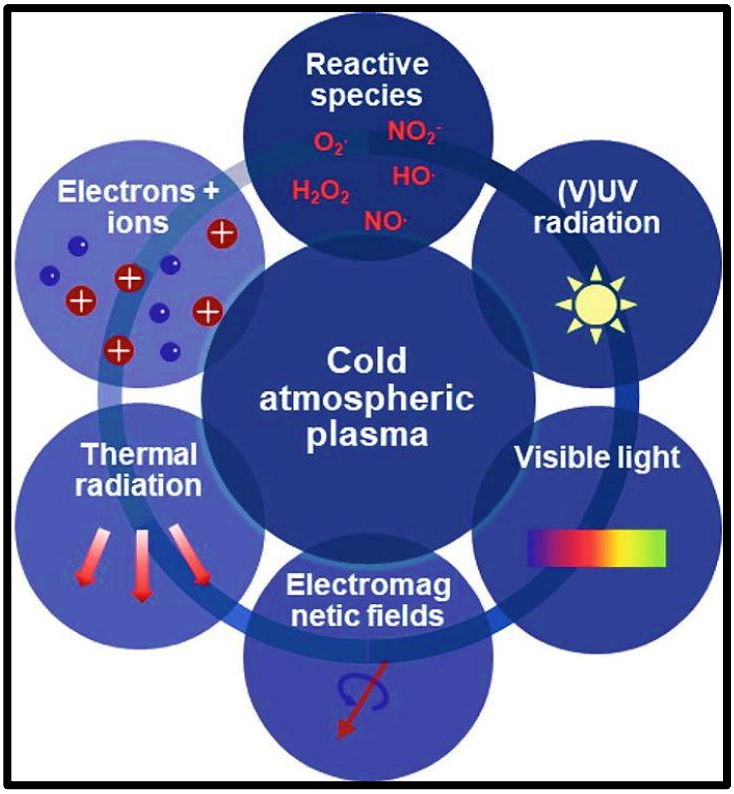

Figure 6: Components of CAP
Courtesy: Smith J. Cold Physical Plasma: A Short Introduction. In: Doe J, Roe R, editors. Textbook of Good Clinical Practice in Cold Plasma Therapy. City of Publication: Publisher; 2022. p. 37–62.

To study CAP, various measurement technologies are utilized, including optical emission spectroscopy for analyzing gas discharges, Rayleigh and Raman spectroscopy (**Figure 7**) for determining electron parameters, mass spectroscopy, and Stark spectroscopy. Additionally, modeling and simulation of plasma reactions further enhance the understanding of how plasma reactive species are generated.[38]

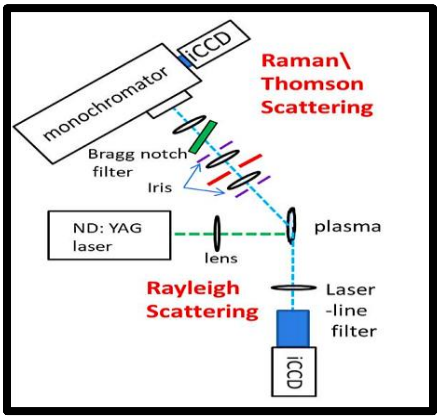

Figure 7: Rayleigh and Raman spectroscopy
Courtesy: Princeton Collaborative Low Temperature Plasma Research Facility. Princeton Plasma Physics Laboratory, Princeton

CAP-based devices are also employed for treating bioaerosols and fluids, where the plasma interacts directly with water. The longevity of bioaerosols is influenced by water evaporation, which, in turn, affects plasma chemistry.[39]In the treatment of skin diseases, it is crucial to adjust the plasma dose precisely.CAP devices range from small, portable units to larger systems, with design considerations including target surface type, electrical parameters voltage, current, supply frequency, pulse width, and specific biomedical applications.[40]The field of CAP technology is advancing rapidly, with a trend towards integrating it into personalized, portable devices, including those powered by batteries.[41]The implementation of Artificial Intelligence in plasma diagnostics and mathematical modeling of plasma reactions would lead to rapid progression in commercialization of CAP based devices with augmented disinfection efficacy.[42]Furthermore, innovative high-strength materials can used as electrode materials, semiconductor based power sources can be used to increase efficiency of CAP devices while also maintaining cheap manufacturing cost.[43] The plasma torch toothbrush represents a significant advancement in dental care technology, offering several potential benefits that enhance both the effectiveness and comfort of brushing. This innovative toothbrush utilizes a special type of plasma—a form of ionized gas—to revolutionize oral hygiene.[44] Plasma technology generates a stream of charged particles that can help break down plaque and kill bacteria, which are common causes of cavities and periodontal disease. One of the primary advantages of the plasma torch toothbrush is its ability to improve oral hygiene with reduced physical effort.[45]Unlike traditional toothbrushes that rely solely on mechanical scrubbing, the plasma torch toothbrush enhances cleaning power through plasma, which helps to minimize plaque buildup. Additionally, because plasma technology is non-invasive, it provides a more pleasant brushing experience, particularly for individuals who find traditional brushing uncomfortable or have sensitive teeth. The concept of plasma itself has a rich history **(Figure 8).**This review consolidates the diverse applications of non-thermal plasma in dentistry and related fields, highlighting its advantages and areas where further research is needed. It also prioritizes the most impactful and advanced applications of plasma technology, providing a clear overview of its benefits and potential in medical and dental fields.[46]

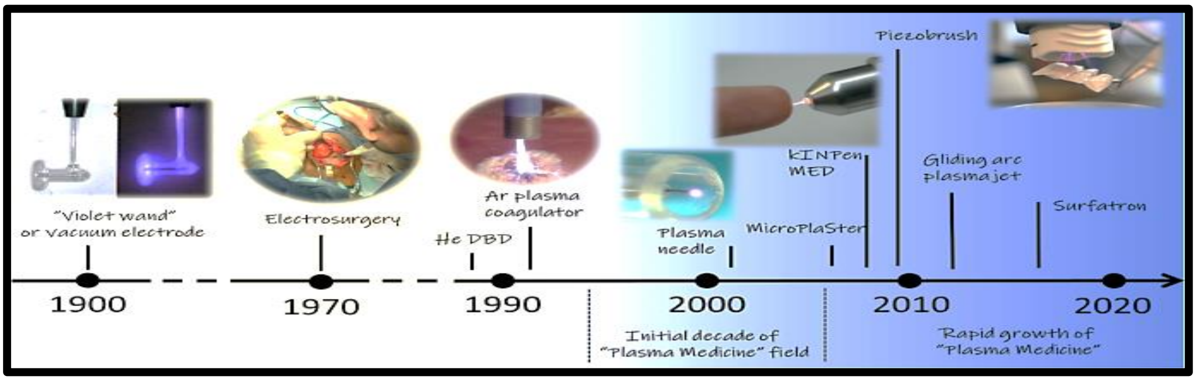

Figure 8–History of concept of plasma application
Courtesy: Koga-Ito CY, Kostov KG, Miranda FS, Milhan NVM, Azevedo Neto NF, Nascimento F, Pessoa RS. Cold Atmospheric Plasma as a Therapeutic Tool in Medicine and Dentistry. Plasma Chemistry and Plasma Processing. 2024; 44:1393–1429.

DISCUSSION

Sterilization is the process of eliminating all forms of microorganisms, including viruses, bacteria, fungi, and bacterial endospores. Common methods for sterilization include steam autoclaving, dry heat, and chemical vapor treatments that use unsaturated chemicals. Among these, autoclaving is the most commonly used method for sterilizing dental instruments. This process involves applying steam under 15 pounds of pressure at 121°C for 20 minutes, or at 134°C for 3 minutes. The steam penetrates effectively, ensuring all surfaces of the instruments are disinfected. Other methods include ovens that use dry heat and chemical vapor sterilizers that operate with unsaturated vapors.[47] Dry heat sterilization requires exposure to temperatures between 160°F and 170°F for 1 hour to achieve microbial kill. However, thermal sterilization techniques may not be suitable for all dental materials, and chemical sterilization can sometimes cause undesirable changes in materials and instruments.[48]Plasma sterilization has emerged as an advanced non-thermal method, surpassing traditional techniques. Its effectiveness depends on various factors such as the gas composition, bacterial strain, and driving frequency.[49] Plasma devices have shown a faster bacterial kill rate compared to conventional non-thermal methods.[50] The mechanism of plasma sterilization involves multiple active components, including reactive ROS, electromagnetic fields, UV radiation, ions, and electrons. These components interact with bacterial cell membranes, specifically targeting unsaturated fats and proteins involved in membrane transport.[51]Hydroxyl radicals generated by plasma disrupt membrane lipids, leading to bacterial inactivation. Plasma also affects the area surrounding the contact site. Although plasma sterilization technology is increasingly popular in biomedical applications **(Figure 9)**and may soon find use in dentistry, its application for decontaminating surgical instruments is still limited.[52]According to Whittaker et al., plasma gas cleaning could effectively reduce the amount of proteinaceous compounds on endodontic tools and files, potentially preventing cross-contamination between patients.[53]Li et al. have indicated that plasma sterilization addresses the limitations of existing methods due to its safety, thoroughness, speed, and low temperature.[54] Sung et al. evaluated the performance of non-thermal plasma devices for sterilizing metal, rubber, and plastic equipment, finding them highly effective in deactivating Bacillus subtilis and E. coli, with superior results against E. coli compared to UV sterilizers.[55]Additional studies by researchers such as Socransky et al. have demonstrated that plasma can inactivate a range of bacteria, including Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, and Enterococcus faecalis.[56]The review of literature highlights that non-thermal plasma is an effective sterilization method for dental instruments and various dental surfaces due to its powerful bactericidal properties. Compared to traditional sterilization techniques, non-thermal plasma is not only more efficient but also significantly faster and more thorough.[57] Its versatility allows it to be used on a range of materials, from plastics and glass to metals, which reduces the need for multiple sterilization and disinfection processes. This streamlines procedures, saving both time and resources.[58]

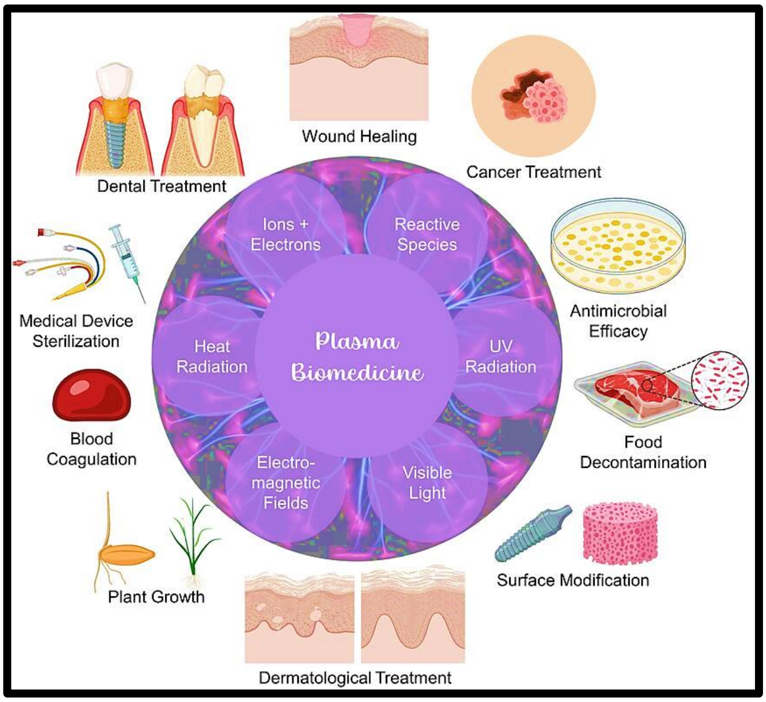

Figure 9- Biomedical applications of CAP

Courtesy : Ercan UK, Ozdemir GD, Ozdemir MA, Guren O. Plasma medicine: The era of artificial intelligence. Plasma Process Polym. 2023; 20(12).

Dental Caries: Mechanical and laser methods are commonly used to clean and disinfect infected tissue in tooth cavities or root canals. However, both approaches can potentially damage healthy tissue due to heat and vibrations. These factors can increase patient discomfort, anxiety, and fear of dental procedures.[59] CAP offers an alternative by decontaminating cavities without the need for drilling. Despite its surface-level application, the active plasma species can penetrate deeply into the cavity.[60]Clinical procedures involve disinfecting bacteria within dentine tubules or near the pulp after removing the bulk of soft carious tissue with bur. It being vibration-free reduces patient pain perception and are especially beneficial for children or patients apprehensive about traditional drilling methods.[61]Although clinical evidence is still forthcoming, plasma technology shows promise in facilitating the removal of necrotic or non-remineralizable tissues through its indirect application**(Figure 10).**[62]Raymond et al. investigated the interactions between non-thermal plasma and tooth tissue using a plasma needle and found it effective for microbial decontamination.[63]Unlike lasers or conventional mechanical methods, plasma operates at ambient temperatures, preventing extensive tissue damage.[64] Plasma therapy is noted for its ability to preserve tissue, making it ideal for cleaning irregular structures and narrow channels within damaged teeth. The plasma needle generates short-lived chemical species that interact with tooth surfaces, allowing localized bactericidal action. This method avoids the residual presence of antibacterial rinses, directly targeting cavity and fissure areas.[65]Eva Stoffels, a pioneer in plasma needle technology, endorsed its use for its effectiveness against E. coli.[66] Goree et al. provided compelling evidence of non-thermal plasma's ability to eradicate S. mutans.[67]Yang et al. introduced a low-temperature atmospheric argon plasma brush, demonstrating its efficacy in deactivating and decontaminating Streptococcus mutans and Lactobacillus acidophilus. Their studies showed complete eradication of Streptococcus mutans in 15 seconds and decontamination of Lactobacillus acidophilus in 5 minutes.[68]Overall, cold plasma disinfection of dental cavities is highly advantageous due to its ability to eliminate drilling, reduce patient anxiety, and provide a conservative approach to cavity preparation, while minimizing bacterial load and avoiding heat production.[69]

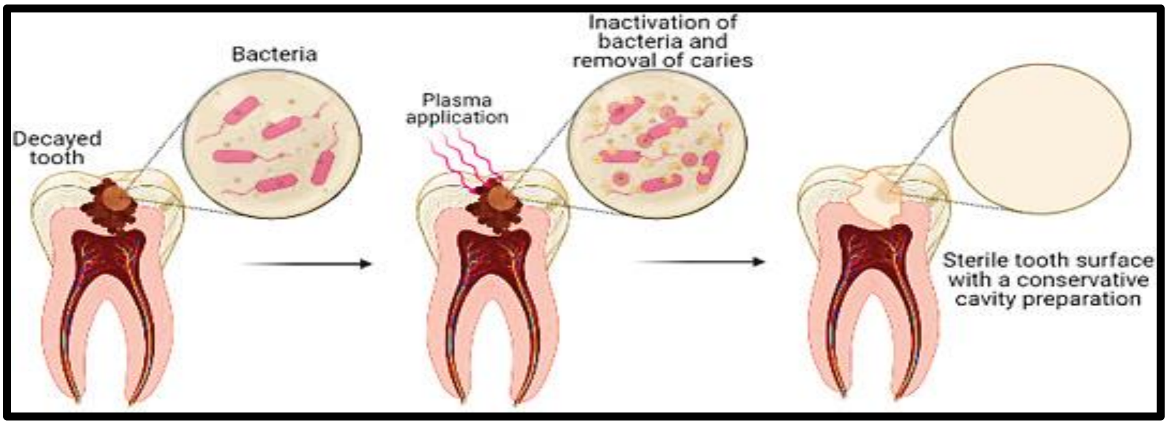

Figure 10– Cleaning and disinfection of carious tooth with plasma
Courtesy: Late S, Chakravorty S, Mitra T, Pradhan PK, Mohanty S, Patel P, Jha E, Panda PK, Verma SK, Suar M. Aurora Borealis in dentistry: The applications of cold plasma in biomedicine. Mater Today Bio. 2022; 13:100200.

Root Canal Disinfection: Successful root canal therapy depends on thorough disinfection of both the canal walls and lumen. Insufficient disinfection can lead to treatment failures due to persistent bacterial infections. Achieving effective bacterial eradication necessitates the removal of the smear layer and disruption of biofilm to expose bacteria to disinfectants. While sodium hypochlorite is commonly used for its strong proteolytic and disinfectant properties, its efficacy is limited by chlorine depletion and ineffectiveness against certain bacteria like Enterococcus faecalis.[70] Traditional disinfectants also risk tissue toxicity and have compromised performance due to surface tension issues, which hinder penetration into complex canal systems. Recent advancements introduce non-thermal plasma as a groundbreaking alternative**(Figure 11).**[71]Studies by Lu et al. demonstrated that a plasma jet device, using Helium/Oxygen gas, can effectively generate plasma within root canals, achieving rapid and thorough disinfection.[72] This technology has proven capable of completely eradicating Enterococcus faecalis within minutes, as confirmed by Li et al.[73]Additionally, Pan et al. emphasized non thermal plasma ability to penetrate areas that conventional methods struggle to reach, highlighting its potential to address previously challenging cases. While promising, further clinical validation is needed to fully establish its efficacy and integration into standard practice.[74]

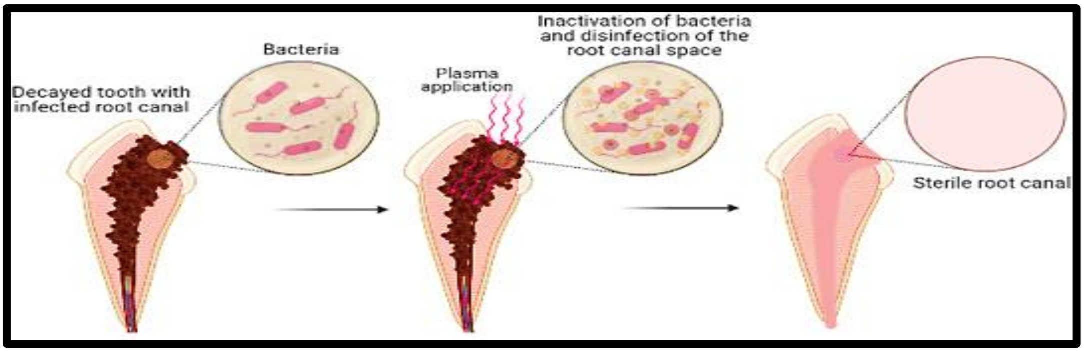

Figure 11 – Root canal disinfection via non-thermal plasma
Courtesy: Late S, Chakravorty S, Mitra T, Pradhan PK, Mohanty S, Patel P, Jha E, Panda PK, Verma SK, Suar M. Aurora Borealis in dentistry: The applications of cold plasma in biomedicine. Mater Today Bio. 2022; 13:100200.

Tooth Bleaching: Traditional tooth bleaching methods, often utilizing hydrogen peroxide, can compromise enamel integrity by increasing surface porosity and roughness. In contrast, plasma-based bleaching methods offer a highly effective and less damaging alternative.[75] Research by Lee et al. revealed that combining atmospheric pressure plasma with hydrogen peroxide effectively removes stains without adverse effects on enamel.[76] Subsequent studies by Park et al., Kim et al., and Nam et al. confirmed that non thermal plasma not only enhances whitening results but also can be safely combined with conventional bleaching agents for improved outcomes.[77]Plasma treatment represents a promising advancement in tooth whitening, offering enhanced efficacy while minimizing damage to dental tissues (**Figure 12,13**).[78]

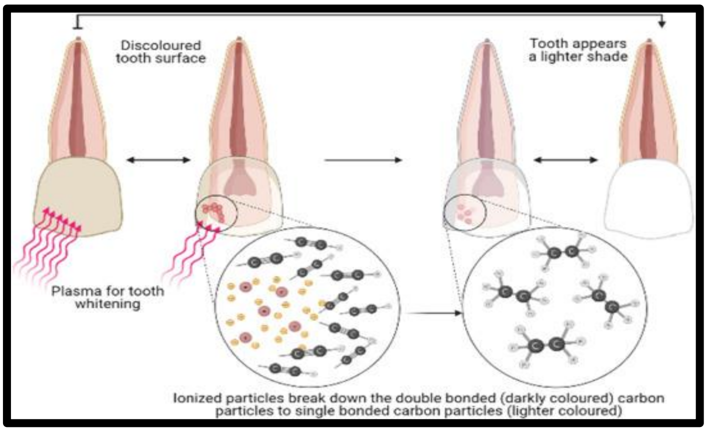

Figure 12: Tooth bleaching using CAP
Courtesy: Late S, Chakravorty S, Mitra T, Pradhan PK, Mohanty S, Patel P, Jha E, Panda PK, Verma SK, Suar M. Aurora Borealis in dentistry: The applications of cold plasma in biomedicine. Mater Today Bio. 2022; 13:100200.

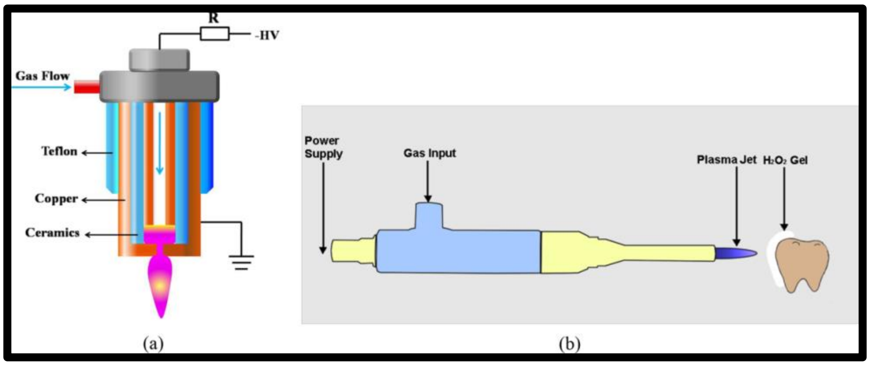

Figure13: Tooth bleaching using CAP
Courtesy: Yang X, Sun K, Zhu W, Li Y, Pan J. Time-dependent efficacy and safety of tooth bleaching with cold plasma and H_2O_2 gel. BMC Oral Health. 2022; 22:535.

Clinical Removal of Biofilms: Biofilms, consisting of microorganisms encased in a polymer matrix, contribute to dental diseases like caries and periodontitis. Traditional methods struggle with biofilm resistance and limited effectiveness in vivo.Non thermal plasma can disrupt biofilm matrices without damaging oral tissues.[79] Rupf et al. found that combining plasma therapy with an air/water spray effectively removes biofilms from dental implants.[80]Studies by Koban et al., Jiang et al., and Schaudinn et al. confirmed that non thermal plasma outperforms traditional disinfectants in biofilm removal, enhancing treatment outcomes for dental infections.[81]

Polymerization: Non thermal plasma can aid in polymerization by enhancing cross-linking and curing speeds. However, there are drawbacks, such as increased residual stresses and polymerization shrinkage. Recent studies have shown that non thermal plasma can effectively polymerize self-etch adhesives, though further research is needed to optimize this process and address potential issues.[82]

Adhesive Restorations: Non thermal plasma improves bonding strength at the dentin-composite interface by increasing the number of free radicals and ions on the tooth substrate. This enhancement is due to the removal of the smear layer and better exposure of type I collagen fibers. Studies by Dong et al., Kong et al., and Ritts et al. demonstrated that non thermal plasma can significantly improve dentin-adhesive bonding strength, leading to more durable restorations.[83]

Post and Core: Non thermal plasma treatment enhances bonding strength and wettability between fiber-reinforced composite posts and resin composites. However, the strength gained from plasma treatment can be affected by aging and is technique-sensitive. Further research is needed to fully understand the effects and optimize non thermal plasma treatment for posts.[84]

Implant Modification: Plasma treatment increases surface roughness and wettability of implants, promoting better cell adhesion and osseointegration. This enhances the success rate of implants by improving integration with the alveolar socket. Plasma's residue-free nature and its impact on surface characteristics make it a valuable tool in implant modification.[85]

Periodontal Diseases: Non thermal plasma shows potential in treating periodontal diseases by enhancing osteoblastic proliferation and promoting osteogenic differentiation of periodontal ligament stem cells. While promising, more research is needed to confirm these effects and their clinical applicability.[86]

Wound Healing: Non thermal plasma may facilitate wound healing by generating reactive species that accelerate the repair process. Its ability to promote cell turnover and reduce complications like dry socket suggests potential benefits for oral wound management. However, additional studies are needed to validate these findings.[87]

Intraoral Diseases: Non-thermal plasma has demonstrated significant effectiveness in addressing intraoral diseases caused by Candida albicans, such as denture stomatitis and angular stomatitis. Despite these promising results, further extensive research is needed to assess its efficacy across a wider spectrum of oral and dental conditions.[88]

Oncology: Non-thermal plasma shows considerable potential in the treatment of oral carcinoma by inducing necrosis and apoptosis in tumor cells while sparing healthy tissue. This method offers a non-invasive alternative to traditional chemotherapy, with fewer side effects and no toxic residues. The vaporous nature of plasma allows it to reach and treat areas that are otherwise inaccessible to conventional tools, such as pits and fissures.[89]Compared to lasers, plasma provides targeted bacterial destruction without causing thermal damage or pain. Although promising, the clinical application of non-thermal plasma in oncology requires further refinement and research to fully establish its effectiveness and optimize treatment protocols. The development of non-thermal plasma technology for dental and medical applications holds great promise.[90] However, significant work remains to create safe, efficient, and environmentally friendly plasma sources. The ongoing research aims to better understand the mechanisms of plasma interaction with cells and to enhance its applications in dental and medical fields. While the potential benefits are clear, advancing plasma technology from experimental to practical use will require continued investigation and development.[91]

Limitations& Challenges of Non-Thermal Plasma in Oral Care: Non-thermal plasma technology in oral care, despite its potential, faces several significant hurdles. Key challenges include application difficulties. The presence of amalgam restorations can complicate the use of non thermal plasma. Additionally, practical issues such as gas flow reaching deep or blocked channels and the inherent difficulty of treating bacteria embedded within tooth enamel need to be addressed. High equipment costs, maintenance requirements, and limited availability hinder widespread adoption. The current marketing and promotion of non thermal plasma are still evolving, impacting its clinical integration.[92]Safety concerns encompass the production of ozone during plasma generation poses inhalation risks for both patients and practitioners. Furthermore, the electric current used in the process can cause discomfort if anesthesia is not properly administered. ROS generated during treatments like bleaching might also damage healthy tissues and complicate the treatment of previously operated teeth or implants. Limited clinical evidence are available in non thermal plasma has shown antimicrobial efficacy in laboratory settings, translating this success to clinical treatments remains challenging. The direct clinical impact on oral tissues, particularly in deep carious lesions, needs further investigation. The primary drawback is the limited availability of necessary materials and equipment. Further research is crucial to develop safe, efficient, and environmentally friendly plasma technologies that are cost-effective and reliable.[93]

Future Directions in Paediatric Dentistry: Plasma technologies hold significant promise for pediatric dentistry. Optimizing plasma torch technology could improve plaque and biofilm removal while ensuring safety for young patients. Combining CAP with traditional oral hygiene methods might enhance cleaning outcomes and reduce plaque formation in children. CAP's potential to target oral pathogens specific to paediatric dentistry, such as those causing early childhood caries and gingivitis, warrants further exploration. Incorporating antimicrobial plasma technology into toothbrushes could lower bacterial loads and mitigate the risk of oral infections. Research should focus on making these tools affordable and accessible; particularly for low-income families.[94]Innovations must ensure that plasma technologies are non-invasive and non-irritating for sensitive pediatric tissues. Efforts should include providing educational resources for parents and training for dental professionals. Longitudinal studies and clinical trials will be essential to establish evidence-based protocols and assess long-term benefits and potential risks.[95]

CONCLUSION

Integration of plasma technologies, such as plasma torch toothbrushes and CAP, into pediatric dentistry represents a promising advancement in oral care. These technologies could enhance plaque removal, reduce bacterial load, and improve overall oral health outcomes for children. Focusing on safety, accessibility, and effective integration into routine care is crucial for realizing their full potential. Continued research and development will be key to overcoming current limitations and ensuring these innovations benefit pediatric patients effectively.

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