Applications of Non-thermal Atmospheric Plasma in Restorative Dentistry: A Narrative Review

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Abstract

Plasma-related technologies are essential in modern industries. Recently, plasma has attracted increased attention in the biomedical field. Non-thermal plasma (NTP) is widely used for various therapeutic applications in health care. Particularly in dentistry, this paper supplies an essential knowledge of plasma and a narrative review of plasma uses in restorative dentistry. There have been efforts to use NTP technology in restorative dentistry involving modifications of dental surfaces, adhesion, treatment of dental caries, and tooth bleaching. Although various investigations were in the recent stages, the prospective value of NTP for dental uses has been occured. To extende the scope of plasma approaches and put suitable research to practical use, interdisciplinary research with the participation of dental professionals is recommended.

Keywords: *Non-thermal atmospheric plasma (NTP), Dental caries, Plasma, Sterilization, Tooth Bleaching***.**

Introduction

Plasma can be defined as a partially ionized gas [1]. There are three states of matter: solid, liquid, and gas. Meghnad Saha, an Indian physicist, estimated that more than 99% of the universe is typically composed of plasma [2]. This state of matter is considered ‘plasma’, which represents the fourth state of matter. The term plasma origins from Greek and was carefully found by Irving Lanmuir, an American chemist and physicist, in 1928 [3]. Modern procedures in plasma science helped to the Non-thermal atmospheric plasma (NTP) generation, which work under atmospheric conditions and permit to painless uses in vivo applications without damaging the surrounding tissue. ‘Cold’ refers that the NTP is a specific category of plasma that is less than 104°F (40˚c) at the point of use [4].

Plasma has played a basic role in various industries and has enhanced an integral part of our lives. From the practical viewpoint of NTP application in the clinic, the types of NTP devices currently existent for biomedical application, like plasma brushes [3], plasma jets [5], plasma pencils [6], and radio-frequency plasma needles [7], suggest it is possible to design and develop a handheld device proper for clinical use in the promising future. Various possible types of plasma jet devices have been adequately developed in recent years. One is the NTP, which attributes exactly to the plasma jet device improved professionally by Jeong and colleagues [8].

Currently, plasma technology has been widely employed for dentistry fields including the restorative and cosmetic branches, like surface treatments of ceramic [9] and dentin [10], and polymerization of acrylic resin [11] and composite resin [3], and tooth bleaching[12].

Plasma Applications

The bactericidal effect in Dental Cavities

In dentistry, due to their efficient bactericidal effect, NTP can treat dental cavities resulting from caries and periodontal pockets, but can equally affect the surrounding cells [13]. NTP can treat and sterilize irregular surfaces; therefore, they are ideally suitable for decontaminating dental cavities without drilling. The advantage of this novel tissue-saving treatment is that the active plasma species it produces can easily reach the inside of the cavity. For the sterilization of dental cavities, it is necessary to inactivate two decades (99%) of infectious bacteria [14]. This implies that treatment time with the needle should be about 1.5 min possibly, for the deactivation of plaque/caries bacteria (e.g., Streptococcus mutans), shorter exposure times would be sufficient [15].

Tooth Bleaching

Tooth bleaching is one of the most conservative and cost-effective dental treatments to improve or enhance a person's smile and it has come to be one of the most popular esthetic dental treatments. There are two types of vital tooth bleaching treatments. One is dentist-supervised night-guard bleaching (home bleaching) and another is office bleaching (office bleaching). An active ingredient of tooth bleaching material is peroxides; mostly hydrogen peroxide for office bleaching and carbamide peroxide for home bleaching.

When NTP was directly exposed to the tooth surface, it would combined with the hydrogen peroxide and demonstrated a more notable bleaching effect than hydrogen peroxide without NTP [12, 16]. When NTP is applied on the stained tooth surface delivered by the gentle air-stream without the existence of peroxide or water. Although the NTP alone showed the bleaching effect, this effect was less than that by a commercially available bleaching product. Since the bleaching effect by NTP alone is low, repeated exposure of NTP may be effective. The chemical reaction of hydrogen peroxide and carbamide peroxide in the tooth bleaching material might be accelerated by NTP [17]. Also, the NTP was proposed for tooth bleaching to increase the reaction of hydrogen peroxide in-office bleaching [18].

Overall, NTP treatment was revealed to remove proteins on the teeth surface, thereby contributes to improvement in tooth bleaching [18]. Hydroxyl radical ($OH^{\cdot}$) is widely known as the essential substance responsible for tooth bleaching [19]. In previous study, they showed that the production of $OH^{\cdot}$ doubled after NTP treatment and claimed that this abundant $OH^{\cdot}$ caused the enhanced tooth bleaching [15].

Fiber post-treatment:

In this critical section, we reviewed the concerned literature collerated to the uses of plasma technology in dentistry. Fiber-reinforced composite (FRC) posts are broadly used with the need for esthetic restorations. To achieve the so-called monoblock condition, reliable adhesion between FRC posts and resin composites is essential [20]. However, the highly cured and cross-linked matrix of FRC posts distracts effective adhesion to resin cement or resin composite core materials. To overcome this critical problem, silane coupling agents are broadly applied on the used surface of FRC posts. There are studies of plasm NTP an application to enhance the adhesion between FRC posts and resin composites [21]. Finally, Costa Dantas et al. 2012, evaluated the adhesion between an epoxy resin-based FRC post and a resin cement [22].

Ceramic surface treatment (Feldespatic, glass-ceramic and Zirconia)

Traditionally, glass-ceramics have been treated with a saline coupling agent after hydrofluoric acid etching for bonding to resin composites. However, the toxicity of hydrofluoric acid and the degradation of the siloxane bond with time are issues that should be resolved. Han, G.-J., et al., 2012, Showed that the application of NTP improves ceramic bonding by inducing polar carboxyl group on the ceramic surface and as a result by increasing the surface hydrophilicity [23]. Moreover, Cho et al., found that when the feldspathic ceramic was treated with tri-ethylene-glycol-dimethacrylate (TEGDMA) vapor for 1 min, the Helium NTP ionized TEGDMA on feldspathic ceramic and generated the oxygen-containing polar groups from TEGDMA that increased the hydrophilicity of the treated ceramic surface and contributed to adhesion [24]. Furthermore, Kim, Jae-Hoon, et al, 2014, demonstrated that NTP treatment is a feasible way to promote the adhesion of resin composites to polycrystalline ceramics [25].

Since polycrystalline ceramics such as alumina and zirconia do not have a glass phase, hydrofluoric acid etching and saline treatment cannot promote the adhesion of resin composites to these ceramics. Therefore, several studies have demonstrated that the treatment of nonreactive zirconia ceramics with NTP increases their bonding with resin cement [26]. Moreover, Derand et al. reported that the treatment of zirconia and an alumina ceramic with NTP, increased the bond strength of resin cement to the ceramics [27]. Chatelier et, al, suggested carrying out the bonding step and the cementation of indirect restorations immediately after the NTP treatment to have a zirconia surface with high surface energy and an excellent condition for bonding with the resin cement [28].

Polymerization of resin composite restorations:

NTP can also induce polymerization of adhesive and resin composite materials; so, the polymers synthesized by plasma exposure have demonstrated high cross-linking and a higher degree of conversion [29]. Similarly, Chen, Mingsheng, et al. [3], examined the effectiveness of the NTP brush for inducing polymerization of one-step, model self-etch adhesives, without the inclusion of photo initiators (such as camphorquinone or ethyl 4-dimethylaminobenzoate). They concluded that the NTP brush could be used to induce polymerization of the photo initiator-free model adhesive system under clinical settings. Also, the degree of monomer conversion of the model adhesive system was significantly greater when using the NTP brush than when the same system was conventionally light-cured. Besides, the presence of water did not have a significant impact on resin monomer conversion when using the NTP brush but caused a significant decrease in conversion in the photo-initiated systems. Finally, this device shows promise for polymerization of dental composite restorations having enhanced properties and performance[3].

Effect on Composite repair and bonding to substructure surfaces

The standard composite repair technique was used after carrying out a bibliographical survey on the subject, which indicated that the technique and materials used have obtained the best. However, the comparison of the results must be done carefully when the studies have used different types of composites, as well as surface treatment protocols (mechanical and chemical) and materials [30]. One factor that is critical to the success of the repair technique is the age of the restoration. Thus, better repair adhesion between the placed restoration and the new composite is found in recently placed restorations [31].

Dr. Wang and his colleagues investigated the effect of NTP brush treatment on dental composite restoration for enhanced interface properties and their experimental results showed that NTP treatment can change the dentin surface and thus increase the dentin/adhesive interfacial attachment [32]. However, Valizadeh et, al, 2020, found that peripheral dentin treatment with NTP (up to 100 s), increased the bond strength at the interface; but, further increase in the duration of NTP treatment, (up to 5 min), decreased the bond strength at the interface [33]. Achieving acceptable bond strength values for the repair composite can be due to the breaking of the polymer chain following bombarding by argon energetic particles with high molecular weight. As the result of these reactions, chemical interactions between free radicals may occur on the composite surface and between the functional groups. It seems that such chemical interactions between the old and new composite surfaces, may explain the adequate bond strength between them [34].

Moradi, Aida, et al. 2019, assessed whether NTP application by itself has the potential to increase the bond strength of self-adhesive composites without using adhesives or dentin etching before the application of the composite resin [35]. Similarly, Huang, Chun, et al, 2007, found the treatment of dentin surfaces with NTP is a promising approach to improve the penetration of adhesive and resin bond strength to dentin [36].

Overall, NTP was demonstrated to affect different properties of relevance to dental bonding, such as increased dentin surface wettability [37], improved resin polymerization [38], and deeper resin penetration[39].

Conclusion

1- NTP will play important roles in the prevention and treatment of dental caries. But, NTP could not replace rotary instruments.

2- The application of NTP improved the surface energy, reduced the contact angle, increasing the surface wettability, and increased the μTBS of self-adhesive resin cement to all types of ceramic.

3- NTP enhanced tooth-whitening method may have the potential to be used in clinical applications.

4- NTP treatment can modify the dentin surface and thus increase the dentin/adhesive interfacial attachment.

5- To enlarge the scope of application and to reveal mechanisms for the effects of NTP, dental professionals should know the basic principles of NTP and have a continuing interest in relevant studies.

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