Review Article

Graphene: An Advanced Nano Material in Dentistry

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ABSTRACT

Graphene is a material that defies expectations with its remarkable qualities. Graphene, a single-layer carbon material, exhibits exceptional properties such as high strength, electrical conductivity, and thermal conductivity. Its unique electronic structure and versatility make it a promising candidate for a wide range of applications. This paper explores the potential of graphene that can be used in the field of dental sciences. Despite challenges such as mass production and cost, graphene's promising outlook suggests its significant role in shaping future technologies.

Key-Words: Dentistry, Graphene, Nanomaterials

INTRODUCTION

Nanotechnology is a multidisciplinary field of research spanning several diverse disciplines, such as biology, chemistry, engineering, materials, medical science, and physics. In particular, nanotechnology involves the creation and development of novel materials and devices through the manipulation of properties and functions of matter at the nanometer scale[1]. Nanomaterials have showed wonderful performances in improving the strength and resist wear of tooth fillers and sealants. Moreover, nanomaterials also performed excellent antimicrobial properties in the application of restorative materials (Sharan et al., 2017). Among various nanomaterials, graphene, as a promising two dimensional (2D) carbon-based nanomaterial, is the thinnest and strongest material. In 2004, it was first isolated by Novoselov and Geim using mechanical exfoliation with a sticky tape and they won the Nobel Prize in 2010 (Novoselov et al., 2004). Graphene based materials could be divided into four categories: single-layer graphene, few-layered graphene, graphene oxide (GO) and reduced graphene oxide (rGO) (Bei et al., 2019). Owing to perfect physical properties, well electrical conductivity, and excellent biocompatibility, graphene and its derivative have attracted much attention in the field of medicine and biomedical fields. Moreover, the graphene and its derivatives have also aroused great attentions in the field of dentistry and tissue engineering, dental implant coatings, bone cements, resin additives, and tooth whitening.[2]

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Chemistry About Graphene

Graphene is an ultimate incarnation of the surface: It has two faces with no bulk in between. Although this surface's physics is currently at the centre of attention, its chemistry has remained largely unexplored. What we have so far learned about graphene chemistry is that, similar to the surface of graphite, graphene can adsorb and desorb various atoms and molecules (for example, NO2, NH3, K, and OH).[3,4] An alternative to the surface chemistry perspective is to consider graphene as a giant flat molecule (as first suggested by Linus Pauling). Like any other molecule, graphene can partake in chemical reactions. The important difference between the two viewpoints is that in the latter case, adsorbates are implicitly assumed to attach to the carbon scaffold in a stoichiometric manner—that is, periodically rather than randomly.[5]

Synthesis of Graphene-Based Nanomaterials

Graphene generally can be synthesized from both top-down and bottom-up routes. The top-down route includes micromechanical cleavage of graphite, liquid-phase exfoliation, and chemical exfoliation of graphite to produce GO, followed by chemical or thermal treatments to obtain rGO or TRG, Graphene generally can be synthesized from both top-down and bottom-up routes.[6] The top down route includes micromechanical cleavage of graphite, liquid-phase exfoliation, and chemical exfoliation of graphite to produce GO, and

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followed by either chemical or thermal treatments to obtain rGO or respectively. The bottom-up fabrication route includes chemical vapor deposition and epitaxial growth on the SiC substrate.[7]

Dentistry-Related Property of Graphene and Its Derivatives

1. Biocompatibility and Cytotoxicity

To develop the application of graphene-based materials in dentistry, it is necessary to evaluate the biocompatibility and cytotoxicity of graphene-based materials (Olteanu et al., 2015). Many researchers have been discussed the cytotoxicity of graphene and its derivatives. Up to date, the affected factors involved concentrations, surface functionalization, and so on.[8]

2. Antibacterial Property

As an excellent biomaterial in dentistry, low cytotoxicity and multi-differentiation ability are necessary. Except for these, antibacterial property cannot be ignored. The antibacterial effect of graphene-based materials was firstly discovered by Hu et al. (Hu et al., 2010). Then, more and more researchers had confirmed the antibacterial effect.[9]

3. Stimulation of Cell Differentiation

Ideal biomaterials in the tissue engineering show the ability to induce the adherence, proliferation, and differentiation of cells.[10] Many in vitro studies have shown that graphene and its derivatives showed the multi-differentiation ability such as osteogenic differentiation and regeneration of dental pulp. Similarly, periodontal tissue engineering also required scaffolds to achieve an ideal therapy for periodontitis.[11]

DENTAL APPLICATIONS OF GRAPHENE-BASED MATERIALS

With the improved synthesis methods, expanded types of graphene-based materials, and engineered properties, various applications have been collected and discussed as follows. In addition, a main summary of graphene-based materials used in the dental field:

1. Tissue Engineering

Tissue engineering is widely used in the repair and regeneration of various defects caused by tumour, traumas, infections, and so on.[12] It is well known that the scaffolds provide a platformforthe attachment, proliferation, and differentiation of different stem cells in the tissue engineering. Many researchers proved that graphene-based materials were suitable for fabricating or coating for scaffolds in the tissue engineering.

2. Dental Pulp Regeneration

The neural and odontogenic differentiation induced by graphene-based materials were also observed. Graphene dispersion can be applied.[13]

3. Periodontal Tissue Regeneration

As we know, periodontitis is an inflammatory disease with dramatic destruction in periodontal tissue such as periodontal ligament, alveolar bone, and cementum. With the deterioration of periodontitis, the tooth faced the fate of losing, which led to many functional disorders.[14] Therefore, it is quite urgent to regenerate and appealed many researchers. Compared with graphene and rGO, GO showed the hydrophilic surface and good dispersibility, which facilitated the absorption of some related proteins.[15]

4. Adhesives, Cements and Silane Primer

Adhesives and cements are two kinds of common materials in the dental restorations. Although they showed the advantages of aesthetic effect and high hardness, the problems of high polymerization shrinkage and bad antibacterial property limited their development.[16] Silane primer played an important role in the bonding of zirconia. Owing to various advantages of graphene-based materials, it has been applied to reinforce the properties of adhesive materials (Farooqetal.,2021). Graphene nanoplatelets (GNPs) are usually prepared as fillers of polymer dental adhesives because of the anti-microbial and antibiofilm activity. The nano composites filled with GNPs have been shown to effectively inhibit the active of S.[17] Mutans cells without compromising the bonding properties. When graphene nanosheets were added to two kinds of calcium silicate cements in powder form of different proportions, GNP–cement composites do well in shortening the bonding time and increasing the hardness of both cements.[18] However, the bonding properties of one cement named Endocem Zr (ECZ) were impaired significantly, indicating that the addition of GNPs may improve the physio-mechanical properties of materials but not ideal for all materials in terms of bonding properties (Nileshkumar et al., 2017). Unlike gray GNPs, bright white fluorinated graphene (FG) may be better filler in dentistry. FG has been used to the modification of GICs, presenting great advantages on the mechanical, tribological, and antibacterial properties. Compared with traditional GICs, the composites not only increase the Vickers micro hardness and compression strength but also decrease the friction coefficient. In the antibacterial properties, the GIC/FG composites achieve good antibacterial properties against Staphylococci aureus and Streptococcus mutans.

5. Coatings for Dental Implants and Abutments

Titanium and its alloys have been widely used in dental implants, owing to their various advantages such as good biocompatibility, high mechanical property, and corrosion resistance (FeRidoun et al.,2017; Jeong et al.,2017;Xie et al.,2014).However, implant failure still occurs. Because of the poor osseointegration and peri implantitis of titanium and its alloys (Berglundh et al., 2019; Smeets et al., 2014; Kordbacheh et al., 2019).[19]

6. Teeth Whitening

As we know, hydrogen peroxide (H_2O_2) has been widely utilized for in-office whitening for a long time. The H2O2 molecules can penetrate deep the teeth and carry out the bleaching process. However, the relative high concentrations of H_2O_2 caused some side effects such as tooth sensitivity and gingival irritation (Carey and Clifton, 2014; Kwon and Wertz, 2015). Therefore, many improved strategies have been made to accelerate the tooth whitening and decrease the side effects. Su et al. reported a cobalt (Co)/tetraphenylporphyrin (TPP)/rGO nanocomposite, which showed better tooth-whitening efficacy stained with dyes, tea, and betel nuts compared with the H_2O_2 only (I Hsuan et al., 2016). In addition, H2O2 produces an extremely short lifetime of the active free radical. Therefore, to achieve a good bleaching effect, H_2O_2 must first penetrate into the teeth and quickly produce active free radicals. However, the Co/TPP/ rGO nanocomposite can be used as a catalyst to produce more reactions between the staining molecules and H_2O_2, which accelerate the bleaching process. In summary, graphene-based materials are a promising catalyst for tooth whitening application with proper types and concentrations.[20]

7. Inhibition of the Growth of Fungal

Peri-implantitis is a common reason for the failure of dental implant. In addition, Candida albicans was found in the31%peri implantitis sites, which quickly attracted much attention (Schwarz et al., 2015). The species of Candida albicans in peri implantitis patients were five times more than the health individuals (Alrabiah et al., 2019; Alsahhaf et al., 2019). Moreover, owing to the high resistant property of Candida albicans, the antifungal treatments are usually failure. The modification of dental implant coatings is a good method to prevent the formation of biofilms. Agarwalla et al. constructed a graphene nanocoating for twice (TiGD) and five times (TiGV) to evaluate the inhibition properties of Candida albicans biofilms (Agarwalla et al., 2020). According to XTT reduction assay, TiGD and TiGV group showed a lower absorbance compared with the control. Then, the colony-forming unit assay that displayed less viable yeast units on the TiGD and TiGV groups at all time points, indicating the inhibition effect of graphene on the fungal biofilm formations[21]. Biosensor for Biomarker Detection From Saliva Dental disease diagnosis can reduce the mortality rates of some serious diseases and improve the quality of life of patients. Owing to its superior electrical and mechanical ability, graphene-based materials are widely used on dental disease diagnosis (Goldoni et al., 2021). Detection of Bacterial and Viral Markers In 2012, Mannoor et al. made the first graphene nano-sensors on tooth enamel (Mannoor et al., 2012). They fabricated a graphene sensing element with wireless readout coil attached to the silk fibroin and then transferred onto tooth enamel. The specific biological recognition was acquired by self-assembling AMP graphene peptides onto the grapheme.[22]

8. Prevention of Enamel and Dentin From Demineralization

White spot lesion (WSL) is one of the most common side effects of orthodontic treatment, which is caused by enamel surface demineralization (Bishara and Ostby, 2008; Nam et al., 2019). Therefore, it is of great significance to overcome WSL in the process of orthodontic treatment. Nowadays, many researchers are focusing on the studying of new bonding agent composites to prevent enamel demineralization caused by bacteria. Owing to the prominent antibacterial activity of GO, Lee and his colleges added GO to a bioactive glass (BAG) (Lee J.-H. et al., 2018). With the increase of GO concentrations, the length of anti demineralization of the GO group increased. Besides, GO containing groups also showed superior antibacterial effect after 24 and 48 h. The anti-demineralization mechanism of the composites may be attributed to the synergic effect of antibacterial effect of GO and the ion-releasing effect of BAG. In conclusion, GO is a promising addition in the anti demineralization of enamel in proper style.[23]

9. Drug Delivery

There is close interaction between bacteria and dental caries, and endodontic and periodontal diseases. Several groups of bacteria that require a common antibacterial strategy are usually involved. Amoxicillin (AMOX) is a kind of broad-spectrum antibiotic that is the first-choice antibiotic in the treatment of endodontic infection in Asian and European countries. In the conditional paste, the dose is not accurately controlled (Nan, 2016). Drug carrier can realize the gradual releasing of antibiotic drugs to easily achieve effective drug concentrations in the infected site. Trusek et al. found that GO had the potential in acting as a drug carrier especially in the therapy of dental inflammation (Trusek and Kijak, 2021). They linked the AMOX to GO using a peptide linker, which is Leu-Leu-Gly and then dispersed in the hydrogel. AMOX was released by enzymatic hydrolysis, showing the effective release of AMOX and the inhibition of bacteria strain growth.[24]

CONCLUSION

Graphene-based nanomaterials offer promising potential for revolutionizing dentistry. While their unique properties, such as exceptional strength, conductivity, and biocompatibility, make them ideal candidates for various dental applications, several challenges must be addressed before widespread adoption. Despite these hurdles, the potential benefits of graphene-based materials in dentistry are significant. They could lead to the development of more durable dental restorations, improved diagnostic tools, and innovative therapies. Further research and development are essential to fully realize the potential of graphene in this field and to establish its safety and efficacy for clinical use.

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