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ROLE OF GRAPHENE IN DENTISTRY: TRANSFORMING THE FUTURE OF ORAL HEALTHCARE

Dental Science

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ABSTRACT

Graphene, a cutting-edge nanomaterial characterized by its exceptional mechanical strength, biocompatibility and antimicrobial properties is gaining increasing attention in dental research and material science. Its integration into various dental applications has demonstrated potential to enhance the performance, durability and biological response of restorative materials, endodontic sealers, implants and regenerative scaffolds. This article outlines the general advantages of graphene in dentistry and explores its specific roles across key dental specialties.

KEYWORDS

Nanomaterial; Graphene; Dentistry

INTRODUCTION

Hummers prepared graphite oxide in 1848, which was again introduced by Brodie et al. in 1958. In 1962, reduced Graphene Oxide (GO) was produced by reducing graphite oxide. Boehm et al. proposed the term graphene to describe the single-layer structure of graphite-like carbon in 1986. Multiple layers were introduced in 1999 by Rouff et al. Graphene a crystalline form of carbon was isolated in 2004 by Novoselov and Geim. It consists of a single layer of hybridized carbon atoms arranged in a two dimensional honeycomb lattice; this fundamental unit repeats itself to form a planar crystalline structure called "sheet". [1]

A honeycomb-like lattice of carbon atoms that have undergone sp^2 hybridization makes up graphene. The six-membered rings piled parallel make up its structure and there are no chemical groups on its surface. [2]

The graphene forms include: graphene nanoplates, nanoflakes, powder, thin sheets and foam.

It can be synthesized by two approaches: top-down and bottom-up. The top down approach consists of production of graphene by separation, peeling, cleavage or mechanical, electrochemical, solvent-based exfoliation of graphite or its derivatives.

The bottom-up approach, instead, includes standard techniques such as chemical vapor deposition, pyrolysis, chemical synthesis, arc discharge, decompression of carbon nanotube, solvothermal, epitaxial growth and electrically assisted synthesis. [2]

Graphene has several fields of implementation including engineering, electronics, energy, biomedical area and dentistry.

General Applications of Graphene in Dentistry [3]

Graphene's versatility offers a wide range of applications in the dental field, including:

- **Antibacterial Properties:** Graphene exhibits significant antimicrobial activity against a variety of oral pathogens, including Streptococcus mutans and Porphyromonas gingivalis by physically damaging the microorganisms via penetrating the cell membrane to induce mechanical stress and by dissolution of phospholipids from lipid membranes. It is also capable of producing oxidative stress. This makes it highly valuable in preventing biofilm formation.
- **Mechanical Reinforcement:** Incorporating graphene into dental composites, cements and coatings significantly improves their mechanical strength, wear resistance and durability.
- **Osteoinductive Properties:** Graphene enhances osteogenic differentiation, making it useful for bone regeneration, particularly in dental implantology and periodontal therapy.
- **Drug Delivery Systems:** Its large surface area and functional groups allow for the controlled delivery of therapeutic agents, including antibiotics, anti-inflammatories and growth factors.
- **Biocompatibility:** Graphene-based materials have shown promising biocompatibility with oral tissues, including gingival fibroblasts and dental pulp cells.
- **Biodegradibility:** The fate of graphene in vivo can be determined by how it is degraded. Several studies and investigations have concluded that neutrophils are capable of degrading highly dispersible graphene.

Application of Graphene in Various Dental Specialties:

1) Oral Medicine and Radiology- GO plays a significant role due to its exceptional physicochemical properties. It is used in biosensors for the early detection of oral diseases, including oral cancer and periodontal infections, owing to its high sensitivity and bio-compatibility. In radiology, GO serves as a potential contrast agent and radioprotective material, enhancing imaging quality and reducing radiation damage during therapy. Additionally, its application in drug delivery systems and tissue engineering supports targeted treatment and oral tissue regeneration. [4]

According to Goldoni et al., GO is used as biosensor for the detection of dental pathologies and can enhance patient's quality of life.

GO is used as drug delivery vehicle incorporated in titanium implants has proved to be a promising drug delivery method in biomedical and pharmaceutical applications. [4]

2) Endodontics- The inclusion of GO to bioactive materials was reported to improve their physio-mechanical properties, cell proliferation and mineralization potential pertinent to their clinical use. It has hydrophilic oxygen functional groups and a high surface area that enhances its role as a endodontic root canal sealer by binding to dentin and seals against micropenetration.[4]

GO exhibits inhibition of growth against wide bacterial species due to its nano-knives property by penetration and disruption of the membrane and is regarded as a quite potential material as root canal irrigant. A novel root canal irrigant which incorporates graphene into silver nanoparticles showed similar efficacy as 3% sodium hypochlorite solution and exhibited less cytotoxicity to the bone and soft tissues than the latter. [5]

GO is used as an intra canal medicament as it promotes tissue healing and regeneration in root canal treatment by stimulating the proliferation and differentiation of dental pulp stem cells. This regenerative property supports the healing of periapical tissues and aids in the repair of damaged dentin and pulp, making it a contributor to biological healing in endodontic therapy.

By modifying Indocyanine green with GO for photodynamic therapy, a significant reduction in the population of E. faecalis was observed, along with improvement in its bioavailability, stability and prevention of degradation. [5]

According to Singh et al., a novel root canal obturating material made up of polymer nanocomposites incorporating GO and found that it had improved antimicrobial activity and mechanical properties than commercial gutta percha, and reportedly non-toxic to neighboring cells.

3) Restorative Dentistry- The addition of fluoridated graphene leads to increase in microhardness, compressive strength and a reduction of the friction coefficient compared to non-reinforced materials without changing the properties of the glass ionomer cements. This combination also decreases the pores and microcracks in the material's internal structure, along with increasing the antibacterial property, which makes it less susceptible to microbial invasion and erosion disintegration. [6]

4) For Bleaching- A nanocomposite was developed employing reduced GO and cobalt tetraphenylporphyrin to be used as a catalyst for bleaching of teeth. This compound when used with hydrogen peroxide using standard photoactivation, increased the bleaching effect of the latter, along with reducing the treatment time. When both the components were photoactivated together, it created more chemical reactions on the stain molecules on teeth. [7]

Graphene nano sheets were combined with the biodentin and endocem, the addition of the sheets did not interfere in the composition rather it reduced the setting time, increased the hardness and didn't alter the pH of both materials. [8]

Sava et al [9] investigated the properties of composite materials composed of a monomeric mixture of Bis-GMA and TEGDMA with graphene, bioglass, colloidal silica as a reinforcing filler. They observed that in materials with the addition of 5-10% by weight of hydroxyapatite with graphene nanoparticles the Young's modulus, surface hardness and the flexural strength of the material were increased.

5) Pediatric Dentistry- Stainless steel (SS) crowns have long been the gold standard for restoring carious primary teeth. However, modern dental practice increasingly prioritizes esthetics, leading to the adaptation or replacement of SS crowns with more esthetic options such as Bioflx and Zirconia crowns. In addition, Graphene, a newer material has been introduced. Graphene crown possess high strength and esthetics. It possesses biocompatibility and prevents immune reaction provocation. It inhibits plaque formation and reduces recurrent decay. [10]

6) Prosthodontics- Acrylic resins, mainly included polymethyl methacrylate (PMMA), have been used for a long time ago as a provisional material in prosthodontics. Their main disadvantages is poor resistance to wear and tear and volume shrinkage after the polymerization. The incorporation of carbon nanotubes, such as GO, in acrylic resins may enhance the resin's mechanical properties and decrease the degree of contraction during polymerization. They exhibited better antimicrobial-adhesion effects, increased hydrophilicity and inhibition of fungal growth.[11]

7) Oral Implantology- The biocompatible nature of titanium shows a very high success rate when used as a dental implant in the oral cavity. However, many scientists are working on various attempts to produce effects beyond the nature of titanium. Titanium coated with the GO film was expected to exhibit beneficial antibacterial properties and deposition of GO using nonthermal atmospheric-pressure plasma promotes bone growth in the vicinity of the implant by enhancing osteoblast cell differentiation.

By using GO as a coating on the implant surface it decreases the peri-implantitis by formation of reactive oxygen species that damage the cell membranes and prevents the adhesion and biofilm formation on implant surface.[12]

8) Periodontics-GO is also used to make barrier membranes and scaffolds for periodontal tissue regeneration. A titanium membrane was coated with GO in a study conducted by Radunovic and concluded the antibacterial effect, GO-Ti membrane did not produce toxic or inflammatory effects. Scaffolds based on hydroxyapatite, chitosan, and GO promoted cell adhesion, proliferation and improved osteogenesis.[13]

9) Orthodontics- Graphene-based materials with unique properties can be incorporated into orthodontic adhesives to improve their biological and mechanical properties with the acceptable bond strength and adhesive remanent index.[14]

Future Challenges and Prespective

Despite abundant studies on graphene and its derivatives, it is at an early stage of research and development, calling for some significant challenges to be addressed.

- **Biocompatibility:** While short-term safety is promising, long-term effects are still unclear. Further in vivo studies are needed. [15]
- **Material Standardization:** Inconsistent synthesis methods result in variable biological responses. Uniform production protocols are required. [16]
- **Regulatory Barriers:** Current regulations do not specifically address nanomaterials in dentistry, delaying clinical translation. [17]
- **Commercial Integration:** High costs and scalability issues hinder the inclusion of graphene in mainstream dental products. [18]
- **Clinical Acceptance:** Limited clinician awareness and training on graphene-based technologies slows adoption. [19]

Despite these barriers, graphene remains a promising frontier in advancement of dental science and biomaterials. With advancements in regulation, safety evaluation, and interdisciplinary collaboration, it is poised to become a key material in future dental innovations.

CONCLUSION

Graphene represents a paradigm shift in dental materials science, offering transformative potential across diagnostics, therapeutics, and regenerative strategies. Its unique properties are driving innovations in nearly every dental specialty, paving the way for more durable, effective, and biologically responsive treatments.

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