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Review Article

Graphene: The game changer in dentistry

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ABSTRACT

Oral cavity is an extremely demanding setting. Most dental materials are in intimate contact with oral tissue for a long time; they must be biocompatible for them to have a harmonious interaction with the host while performing the desired functions. Therefore, there is always a huge interest and strong trend in continuous development of dental materials with improvised properties. Over the past few decades, with the discovery of fullerene in 1985 and carbon nanotubes in 1991, carbon based nanomaterials have been merited on the scientific stage. Graphene is one such material. It is the thinnest and strongest material in existence. Graphene, a single-layer carbon sheet with a hexagonal packed lattice structure, has shown many unique properties, it has shown outstanding potential in many research fields including prosthodontics and allied dental specialities. This review includes studies of Graphene published in the English language. The EMBASE and MEDLINE (National Library of Medicine) databases were searched through PubMed. The keywords consisting of “graphene oxide”, “graphene in prosthodontics” and “graphene in dentistry” were used.

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1. Introduction

Dental materials when placed within the oral cavity are in contact with saliva, gingival crevicular fluid, and water. At the same time, it is exposed to high temperature, masticatory forces, and variety of abrasion causing mechanical failures and overtime requiring restoration replacement with extra cost. Therefore, there is always a huge interest and strong trend in continuous development of dental materials with improvised properties.

Nanotechnology, “The manufacturing technology of the 21st century”, is an art of manipulating matter on a scale of less than 100nm to create numerous materials with various properties and functions. Over the past few decades, with the discovery of fullerene in 1985 and carbon nanotubes in 1991, carbon based nanomaterials have been merited on

the scientific stage. The in-depth investigation of graphene conducted by Andre Geim and Konstantin Novoselov in 2004 has proven that graphene was the building block for all graphitic carbon materials such as graphite, diamond, nanoribbons, CNTs, and fullerenes.

Graphene is the thinnest and strongest material in existence. It is mainly composed of two dimensional sheets less than 10 nanometers thick. These sheets are made up of sp^2 hybridized carbon atoms that are bonded in a honeycomb-like lattice.

Graphene family nanomaterials (GFNs) include ultrathin graphite, few-layer graphene (FLG), graphene oxide (GO; from monolayer to few layers), reduced graphene oxide (rGO), and graphene nanosheets (GNS). They differ from each other in terms of surface properties, number of layers, and size. Among other members of graphene family nanomaterial, graphene oxide (GO) is

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one of the most important chemical graphene derivatives which could be produced through energetic oxidation of graphite through Hummers method using oxidative agents. GO has shown outstanding potential in many research fields, including biomedical applications, biomaterials, drug delivery, and tissue engineering, demonstrating its utility in nanoelectronics, composite materials, energy devices (batteries, fuel cells, supercapacitors, and hydrogen storage), sensors and catalysts.

2. Materials and Methods

This review includes studies of GO published in the English language. Abstracts, editorials, letters, and literature reviews. The EMBASE and MEDLINE (National Library of Medicine) databases were searched through PubMed. In the search, the keywords consisting of “graphene oxide” and “graphene in prosthodontics” were used. These key-words would cover as much information about graphene oxide in dentistry as possible without overlooking related researches.

2.1. History of development of graphene

Graphite oxide was prepared by Hummers and Brodie (1948-1958). Later reduced Graphene oxide rGO, was prepared by thermal and chemical reduction of graphite oxide in 1962. Monolayer graphite was prepared in 1970 and term “Graphene” was coined by Boehm in 1986 to describe single layer of graphite like carbon atoms. Geim and Novoselov in 2004 isolated single layer of graphene for which they were awarded Noble prize in 2010.¹

Graphene comprises a single sheet of conjugated sp² carbon atoms with extremely high mechanical strength and elasticity.² Graphene has two derivatives: graphene oxide GO and reduced graphene oxide rGO. GO can be produced by oxidation of graphite. It has functional groups like, carboxyl, hydroxyl and epoxy groups to which many biomolecules can be combined. Pristine (pure form) graphene is produced by several methods: micromechanical exfoliation of graphite, chemical vapour deposition and epitaxial growth on SiC.

2.2. Graphene has been used in the following areas in dentistry

2.2.1. Bone replacement and regeneration

Bioceramics have been used to replace the jaw bones following tumour resection, fractures with bone loss and congenital anomalies of the jaw bones. Bioceramics can be inert composites of alumina and zirconia or bioactive composites with hydroxyapatite and calcium phosphate. Bioceramics stimulate the stem cells or osteoprogenitor cells into osteoblastic like cells resulting in new bone formation. Graphene has been combined with bioceramics to enhance its mechanical strength and improve osteogenesis. Hydroxyapatite (HAp) particles have potential to induce

osteolineage. Graphene has been added to hydroxyapatite as scaffold and to combine other molecules. HAp/GO composites have been combined with chitosan and gelatin to enhance the release of calcium and phosphorus ions. The combination of HAp with GO increases the adhesion to titanium and increases the corrosion resistance. It also increases the fracture toughness and elastic modulus.

2.2.2. Increasing Bioactivity and Mechanical properties of Polymer based composites

A large number of polymer composites are being combined with graphene to enhance their mechanical properties and reduce infection and inflammation. 2D sheet like structure of graphene allows increased interfacial adhesion between the phases and increased fracture toughness. Combination of GO nanosheets with polyvinylidene difluoride increases tensile strength by 92% and Young’s modulus by 192%. Addition of graphene to Polycaprolactone increases the elasticity modulus from 344 to 626 MPa. Chitosan blended with rGO sheets increased the Young’s modulus from 2.4 to 6.3 GPa and tensile strength from 88 to 206 MPa compared to pure chitosan. The addition of GO to chitosan increased the hardness from 0.3 to 1.1 GPa. Addition of GO to Carboxymethyl- Chitosan increased the hardness from 0.05 to 0.18 GPa and elastic modulus from 1 to 2.8 GPa. Combination of graphene with polymers can stimulate stem cell differentiation. Silk fibroin along with GO or rGO can help differentiation of Periodontal ligament stem cells (PDLSC) into cementoblast like cells.

2.2.3. Drug delivery function

Some compounds like GO with N-vinyl caprolactam (GO-PVCL) can serve as carrier for drugs, e.g. camptothecin-antimitotic agent. Such anticancer drug composite with graphene can be placed in the tumour bed after surgical tumour resection to reduce the recurrence of cancer.

2.2.4. Implants

Graphene as additive or coating to metals for dental and biomedical implants: Graphene compounds can improve the properties of the metals such as strength durability and toughness. In one study addition of graphene to copper increased its hardness and modulus of elasticity. Combination of graphene to an alloy of 1%

Al–1%Sn increased its tensile strength. Graphene deposited on titanium nanowires increased the Young’s modulus by 40 times in one study. GO and rGO in combination of various metal and non-metal implants stimulates the stem cell differentiation to osteogenic stem cells. A very interesting study demonstrated that dental pulp stem cells cultured on glass coated with GO stimulated expression of genes expressed by mineral secreting cells. These research observations open a new vista of bone mineralisation of metal bioimplants by adding graphene.¹

2.2.5. Restorative material

Fluorinated graphene has been developed and combined with glass ionomer cement. This combination exhibits antibacterial effect on *Staphylococcus aureus* and *Streptococcus mutans*. Moreover, it makes the composite resistant to friction and increases the compressive and flexural strength. Glass ionomer cement has wide range of application in restorative dentistry, viz. restoration of deciduous teeth, anterior class III and class V restoration, cementation of crowns, restoration of non-caries teeth and for atraumatic restorative therapy. Addition of fluorinated graphene to the glass ionomer cement widens its dental restorative armamentarium.³ The fluorinated graphene demonstrated good fluoride ion release.

2.2.6. Denture base material

Currently used denture base material has many complications, viz. denture fracture and denture stomatitis. Denture stomatitis occurs in 15 to 70% of denture wearers.

For over 80 years the dentures have been made of polymeric materials such as Polymethyl methacrylate (PMMA). PMMA does not possess enough mechanical strength and it may induce inflammatory response in oral mucosa. The cracks and fractures in denture are common and require a replacement or repair of denture. PMMA has low flexural strength. PMMA also lacks significant antimicrobial property resulting in denture stomatitis. Moreover, allergic reaction and hypersensitivity have also been reported with PMMA.

In order to enhance the biocompatibility and mechanical strength two or more materials have been combined to form composites. We can modify or tailor the physico-chemical properties of the composite by altering the proportion of 2 or more constituents of the composites. Various composites are used in dentistry. Graphene has been added to PMMA for enhancing its mechanical strength and reduce the risk of denture stomatitis. Graphene based denture material exhibit significant advantages in terms of antimicrobial property and increased mechanical properties. Graphene has been mixed with nanoparticles of silver and other metals to exhibit antimicrobial effect.

2.3. Properties of graphene

1. **Electric properties:** The charge carriers of graphene behave as massless particles or Dirac fermions.⁴ The graphene behaves as a 2D semimetal and charge carriers move with little scattering. It also exhibits a strong ambipolar effect.
2. **Optical properties:** The white light absorbance of single layer graphene is 2.3% with negligible reflectance. The absorbance increases linearly with layer numbers from 1 to 5. The transparency of graphene depends on fine structure constant $\alpha = 2\pi e$

$2/hc$.

3. **Thermal properties:** The thermal conductivity of the single layer suspended graphene is 3000–5000 $\text{W m}^{-1} \text{K}^{-1}$ at room temperature. When supported on amorphous silica the conductivity of graphene is 600 $\text{W m}^{-1} \text{K}^{-1}$.
4. **Mechanical Properties :** The atomic force microscopy has revealed that graphene is the strongest material. The breaking strength of monolayer graphene is 42 N m^{-1} and the Young's modulus is 1.0 TPa. It has very high surface area to mass ratio = 2630 m^2/g . Its Young's modulus, ≈ 1100 GPa, rendering it a very high mechanical strength.
5. **Antimicrobial property:** Graphene and GO composites have been synthesised in combination with silver or zinc nanoparticles to exert a strong antimicrobial effect against the following bacteria: *Staphylococcus aureus*, *Streptococcus mutans* and *E.coli*. This property has been very useful in reducing the denture induced stomatitis and decreased chances of secondary caries.⁵ Graphene exerts this antimicrobial action by disrupting the cell wall and membranes of the bacterium. Other antimicrobial mechanisms include: wrapping the bacteria by GO sheet, production of reactive oxygen species, and pumping of electrons out of bacterial cell. GO based composites also reduce the chances of biofilm formation on the implants ZnO-rGO composites are highly effective in controlling *Staphylococcus mutans* growth and thereby controlling caries formation.

3. Conclusion

A material composed of a single component cannot comply with all the properties required for dental applications designated by the American Dental Association (ADA) and FDI World Dental Federation specification. However, The invention of Graphene has come as a boon to the reconstructive dentistry. It offers unique physico-chemical properties to the armamentaria of a dentist. Its ability to combine with a number of metal and other chemicals, opens new vistas for repair and replacement of teeth, jaw or other parts of the body. Graphene composites with silver or zinc oxide exhibit strong antimicrobial effect preventing infections associated with foreign body placed in mouth or other organs.

4. Conflict of Interest

The authors declare that there are no conflicts of interest in this paper.


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None.

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