wjpmr, 2021, 8(6), 219-223

SJIF Impact Factor: 5.922

WORLD JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.wjpmr.com

Review Article

ISSN 2455-3301

WJPMR

GRAPHENE - AVANT GARDE IN DENTISTRY

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Article Received on 16/04/2021 **Article Revised on 06/05/2021** **Article Accepted on 26/05/2021**

ABSTRACT

Graphene is an allotrope of carbon which possess the enchantment of being stronger than steel and thinner than paper. Its malleable, transparent, highly conductive and seemingly resistant to most gases and liquids. These exceptional properties of graphene based materials have the potential to revolutionise dentistry through its vast applications. Therefore, based on current knowledge and latest progress, this article aimed to present the recent achievements and provide a comprehensive literature review on potential applications of graphene that could be translated into clinical reality in dentistry.

KEYWORDS: Graphene, Carbon, Dentistry, Biocompatible, Allotrope, Prosthodontics.

INTRODUCTION

Discovery of many materials is ultimately transforming the universe, recently nanoforms are taking the rule. The novel 2D material graphene consists forms of allotrope of carbon as a single layer of atoms in a sp2 2D hexagonal lattice where one atom forms each different vertex honeycomb sheet of carbon atoms. It contains all the basic structural element of different allotrope which includes graphite, carbo nanotubes, charcoals and fullerenes. Its exhibits exceptional physical, electronic, and mechanical properties originate from the two-dimensional (2D) electron confinement within a one-atom-thick layer have shown stunning potential in many fields such as composite materials, nanoelectronics, energy storage, sensors,and in biomedical field such as bio imaging, bio sensing, drug delivery, gene delivery, tissue engineering, cancer therapy and in dental field.

History

Graphene was discovered by Andre Geim and Konstantin Novoselov at the University of Manchester in 2004. Their discovery gave them Nobel Prize in 2010. Novoselov stick a flake of graphite to a scotch tape and then exfoliated it to separate the graphite layers and repeated this process several times to reduce the thickness of graphite until few layers of Graphene sheet was isolated. The term of graphene was recommended by the relevant lUPAC commission to replace the old term "graphite layers" that was suitable in the research of single carbon layer structure, because a three-dimensional stacking structure is identified as graphite.

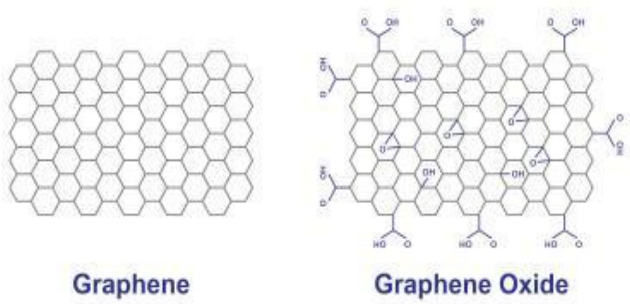

Fig. 1: Structure of Graphene and Graphene oxide.

Properties of grapheme[1,2]

1. Atomic width: Single atom thick ("two-dimensional"), about 0.335 nanometers
2. Electron mobility: Maximum electron mobility with theoretical limit of200,000 cm 2/(V•s) (>100x higher than silicon)

3. Strength: Monolayer graphene is the strongest material ever tested with a strength of 42 N/m.
4. Toughness and Stretchability: Comparatively brittle, it can be stretched by up to25%–highly relevant for flexible electronics.
5. Stiffness: Same as diamond.
6. Impermeability: Even the minimum atom (helium atom) cannot pass through a sheet of graphene.
7. Electrical resistivity: 1x10-8Ω•m among the lowest of any known material at room temperature (~35% less than copper)
8. Thinnest material known, Ultra light material
9. Almost transparent (absorbs only 2.3% of light)
10. Completely impermeable
11. Highest density at room temperature
12. Large surface area (-2600m^2g^{-1})
13. Most stretchable crystal (20% elasticity)
14. Exceptional thermal conductivity and chemical stability (S000W/m.k)
15. High intrinsic mobility(100 times more than in Si)
16. Biocompatible.
17. Antibacterial

Graphene forms

- Graphene nanoplates
- Graphene nanoflakes
- Graphene powder
- Graphene thin sheets
- Graphene foam

Graphene and Its derivatives[3]

Graphene related materials can be classified based on either number of layers (eg.mono- or multi layered)or their chemical modification into

- Graphene oxide (GO)
- Reduced graphene oxide (rGO)
- Nitrogen doped grapheme (N-G)

Graphene oxide (GO) is a highly oxidized form of graphene prepared by oxidation of graphite. Reduced graphene oxide (rGO) can be further reduced to graphene like sheets by removing the oxygen containing groups with the recovery of a conjugated structure.

Applications of graphene

General

Super capacitors
Energy storage
Wireless power
Super sensitive touch screen
Ultra thin batteries
Instant de-icing of aircraft
Nano-scale transistors
Thermo conductive lubricants
Water filtration & desalinization

Applications in Biomedical field

a. Medical applications

1. Graphene based biosensors are used for detection of small biomolecules (dopamine, glucose, etc) proteins and DNA through pi-pi stack interactions. They are also used in bio-imaging, photo thermal therapy, drug delivery, gene delivery, tissue engineering. Some of the reliable ultrafast biosensing platforms are fluorochrome based nano-optical biophonic detection system such as fluorescence resonance energy transfer (FRET).[2]

2. Drug delivery: Graphene oxide and its derivatives exhibits properties used to carry DNA, proteins and antibodies.[4] High surface area of graphene allows high drug loading capacity that can be compared to other nanomaterials. But due to poor rigidity cell penetration, the success of grapheme based drug delivery tool is dependent on three factors such as, a) constructing optimal loading capacity, b) to confirm degree of toxicity and c) designing a system which will be able to release drugs in a controlled manner at the required site(tumour) for successful therapy.[5]

3. Cancer Therapy: Cancer stem cues (CSC) or tumour stimulating cells are resistant to predictable therapeutic approaches. Drug resistant CSC can cause unfavourable chemical outcomes. Studies suggest that GO can also be directly used as a beneficial agent for targeting CSC as a differential agent. GO execute its belongings on CSC by inhibiting numerous key signal transduction pathways. GO can be delivered as a therapeutic agent that will depend on the site of tumour, GO flakes can also be utilized as a lavage solution during surgery, with the aim of preventing tumour recurrence and distant metastasis.[6]

b. Dental application: Different modifications have allowed graphene to be used in various fields of dentistry. Tensile properties of graphene are comparable to bone, enamel and dentin make it a suitable dental restorative material. With good biocompactibilty and aforementioned properties graphene can be used successfully in implant dentistry as well.

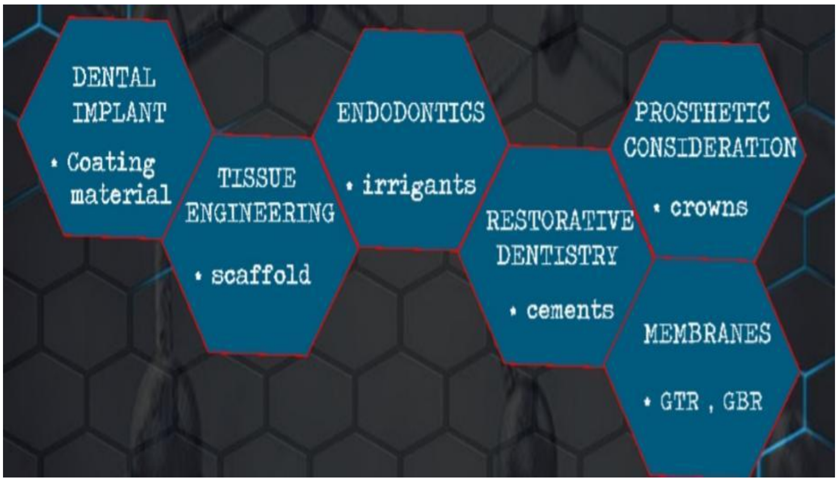

Fig. 2: Application of graphene in dentistry.

1. Detection of Bacteria: Sensors and interfacing electronic devices made of biomaterials like nanoscale materials such as carbon nanotubes, nanowires and graphene are gaining popularity. The single atom thick graphene is of particular interest because of its optical properties as well. Specialization have been made to identify the specific type of organism.[7]

2. Antibacterial activity of Graphene: Streptococcus mutans is the primary gram-positive facultative anaerobic bacteria involved in caries formation while Porphyromonas gingivalis and Fusobacterium nucleatum are Gram-negative anaerobic bacteria associated with periodontitis and root canal infection.A study conducted by He et al. evaluated the antibacterial activity of GO nanosheets against these three common types of bacteria and found that GO nanosheets were highly effective in inhibiting the growth of dental pathogens.[8]

3. In Restorative Dentistry: Natural tooth surfaces are subjected to stresses and wear repeatedly due to forces applied over to the tooth while chewing and masticating. Those surfaces which undergo wear develop caries or produces sensitivity in later period which require restorations as a treatment approach. The commonly used materials like silver amalgam, glass ionomers, composites and ceramics can also undergo wear over a long period of time. In recent years, attempts had also been made to incorporate graphene derived nanomaterial into commercially available glass ionomer for reinforcement.Graphene, when combined with glass ionomer prepared with poly(acrylic acid), has significantly enhanced physiomechanical properties of GIs.[9] Graphene fillers supplementary into restorative materials maximizes the strength and durability of the restoration. Fluoride graphene when prepared by hydrothermal reaction of graphene oxide and mechanically blend with glass ionomer could produce a GICs/FG composites matrix, which could significantly enhance the mechanical, tribological, and antibacterial properties of glass ionomer.[10] With the increase of FG content in glass ionomer, there is a decrease of pores and microcracks in the internal structure of material and an increase in antibacterial ability making it less susceptible to erosion disintegration and microbial invasion.Though ceramics are the best material for indirect restorations their use is limited because of low fracture toughness, poor creep, brittleness. Presence of impurities, pores and cracks can cause pure ceramic extremely brittle. Reinforcing resin polymer matrices with graphene gold nanoparticless, if integrated as fillers in ceramics can also get better surface properties as well as other mechanical properties.[11]

4. Endodontics: Sodium hypochlorite is the most popularly used intracanal irrigant for its strong antibacterial and tissue-dissolving abilities. However, sodium hypochlorite extrusion during root canal treatment causes acute immediate symptoms and its sequelae including rapid hemolysis and ulceration of surrounding tissues etc:[12] Incorporating graphene into silver nanoparticles showed strong antibacterial property, as efficacy as 3% sodium hypochlorite in canal disinfection, but with less cytotoxic effect to bone and soft tissues.[13] Reinforcing MTA, a widely used retrograde filling material with GFNs resulted in an enhancement of their mechanical properties. Bioactive cements like Biodentine (BIO) and Endocem-Zr (ECZ) have been widely used in endodontics for management of perforation, retrograde root filling, and pulp capping. Addition of 3 wt % graphene nanosheets showed significant decrease in setting time of both cements.

5. Bone tissue engineering: Graphene, without signs of cytotoxicity, accelerated the proliferation and differentiation of human mesenchymal stem cells (hMSCs) into bone cells with a rate that is comparable to the one achieved with common growth factors. Major bone rebuilding is a

worldwide health crisis and represents a great challenge.[14] Materials such as polycaprolactone (PCL). But these polymers lack cell adhesion sites and may require chemical modification for stem cell adhesion. Also, their byproducts on degradation can trigger immune response. Because of the differential and significant properties of graphene has as a show's potential material for stem cell research. They allow stem cell adhesion, growth along with they also improve osteogenic segregation. A study conducted by Nishida et al. evaluated the tissue proliferative behaviors in relation to GO scaffold in the tooth extraction socket of dogs. It was observed that a fivefold increase in bone formation happened with GO scaffold than collagen scaffold, which further confirmed the high bone forming capability of GO scaffolds.[15]

6. Periodontal tissue regeneration: In treatment for periodontal bone defects using guided tissue regeneration (GTR) and guided bone regeneration (GBR), barrier membranes have been a crucial to create a secluded space between soft connective tissue and regenerating bone, for formation of unimpeded bone promoting faster differentiation of mesenchymal cells into odontoblast/osteoblast. [16] Radunovic et al. investigated the effect of collagen membrane coated with GO (10 microg/mL) on the viability and metabolic activity of dental pulp mesenchymal cells. The result showed that GO coating at the higher concentration induces PGE2 secretion, controls inflammation, and promotes DPSCs differentiation.[17]

7. Prosthodontics: The promising properties together with the ease of processing and functionalization make graphene-based materials ideal candidates for incorporation into a variety of materials. Graphene can be successfully used in removable prosthesis confection in order to improve mechanical properties of the materials, mainly the polymethylmethacrylate. Although more studies are needed, the results obtained in this investigation are very encouraging. The graphene nanoreinforced biopolymer G-CAM disc, especially designed for permanent dental structures, is available in different chromatic crowns that have an extremely natural aesthetic appearance, as well as resolving all the mechanical, physicochemical and biological failures of the rest of the materials currently used in the sector. The G-CAM discs provide innumerable properties to dental structures and comply with all the necessary requisites to be the ideal material for prosthetic works with CAD/CAM technology.The thickness of the G-CAM disc can be 14, 16, 18, 20, 22, 24 and 26 mm.

8. Coating for implants: Due to graphene's potential osteogenic and antibacterial ability, it appeared to be an excellent implant coating material to favor better osseointegration.When graphene is coated on titanium substrate, the hydrophobic character of graphene film exerted self-cleaning effect on its surfaces decreasing the adhesion of microorganism including S. sanguinis and S. mutans. Additionally,compared to titanium alone, graphene possesses osteogenic property enhancing the expression of osteogenic related genes RUNX2, COL-I, and ALP, boosting osteocalcin gene and protein expression, and consequently increasing the deposition of mineralized matrix.[18]

Advantages

a. It is the thinnest yet the strongest
b. It is a good conductor of heat and electricity
c. It is both pliable and transparent
d. Used in production of high-speed electronic devices
e. Enhance differentiation of stem cells
f. Biocompatible
g. High elastic modulus and limit to ensure that the tensions generated during biting and chewing do not cause permanent deformations, and it is possible to manufacture prosthesis of smaller sections.
h. High deformation resistance and stress limit, thus avoiding the formation of cracks and fractures.
i. High impact resistance, which is useful for removable prostheses.
j. High-abrasion resistance that avoids excessive erosion from cleaning or eating.
k. Increased hardness of the material compared with acrylic resins used in dentistry.
l. Chemically inert and insoluble in oral fluids.

Disadvantages[19]

a. Graphene is prone to oxidative environments in the form of catalyst.
b. Through its jagged edge graphene penetrate cell membrane as well as distrupts normal function
c. Super expensive

CONCLUSION

Graphene has been discovered to have unique properties that could revolutionize the world. The reason graphene is such a beneficial material is due to its 2D like nature and short/strong bonds. It is the strongest material ever discovered; however, its brittle nature cannot be used structurally but only used to reinforce other materials. It is found to have various applications in medical field, further research is needed to ensure its usage in dentistry.

Source of support: Nil.

Conflict of interest: Nil.

REFERENCES

1. Sudipta Sahu et al Revolution of Graphene in Dentistry Indian Journal of Public Health Research & Development, November, 2019; 10: 11.
2. Krishnan Amudha Lakshmi et al The revolutionary era of Graphene in Dentistry-a review RGUHS Med Sciences, 2016; 6: 4.
3. N. Chatterjee, H.-J. Eom, and J. Choi, “A systems toxicology approach to the surface functionality control of graphene-cell interactions,” Biomaterials, 2014; 35(4): 1109–1127.
4. Liu, Z et al. PEGylated nanographene oxide for delivery of water-insoluble cancer drugs. Am Chem Soc, 2008; 130: 10876–10877.
5. Li J, Wang G, Geng H, Zhu H, Zhang M, et al. CVD growth of graphene on NiTi alloy for enhanced biological activity. ACS Appl Mater Interfaces, 2015; 7(36): 19876-19881.
6. Jagged graphene edges can slice and dice cell membranes-News from Brown (https://news.brown.edu/articles/2013/07/graphene). brown.edu
7. Manu S, Hu T, Jefferson D. Clayton, Amartya S, David L Graphene-based wireless bacteria detection on tooth enamel. J of applied science, 2012; 8(7): 220-229.
8. Jianliang He et al Killing Dental Pathogens Using Antibacterial Graphene Oxide ACS Appl. Mater. Interfaces, 2015; 7: 5605−5611.
9. S. Malik, F. M. Ruddock, A. H. Dowling et al., “Graphene composites with dental and biomedical applicability,” Beilstein Journal of Nanotechnology, 2018; 9(1): 801–808.
10. L. Sun, Z. Yan, Y. Duan, J. Zhang, and B. Liu, “Improvement of themechanical, tribological and antibacterial properties of glass ionomer cements by fluorinated graphene,” Dental Materials, 2018; 34(6): 115–e127.
11. C. Sarosi, A.R. Biris, A.Antoniacet al., “Thenanofiller effect on properties of experimental graphene dental nanocomposites,” Journal of Adhesion Science and Technology, 2016; 30(16): 1779–1794.
12. S. A. Farook, V. Shah, D. Lenouvel, O. Sheikh, Z. Sadiq, and L. Cascarini, “Guidelines for management of sodium hypochlorite extrusion injuries,” British Dental Journal, 2014; 217(12): 679–684.
13. D. K. Sharma, M. Bhat, V. Kumar, D.Mazumder, S. V. Singh, and M. Bansal, “Evaluation of Antimicrobial Efficacy of Graphene Silver Composite Nanoparticles against E. faecalis as Root Canal Irrigant: An ex-vivo study,” Int. J. Pharm.Med. Res, 2015; 3(5): 267–272.
14. T. R. Nayak, H. Andersen, V. S. Makam et al., “Graphene for controlled and accelerated osteogenic differentiation of human mesenchymal stem cells,” ACS Nano, 2011; 5(6): 4670–4678.
15. Nishida E, Miyaji H, Kato A, Takita H, Iwanaga T, et al. Graphene oxide scaffold accelerates cellular proliferative response and alveolar bone healing of tooth extraction socket. Int J Nanomedicine, 2016; 11: 2265-2277.
16. S. Pajoumshariati,H. Shirali, S.K. Yavari et al., “GBRmembrane of novel poly (butylene succinate-co-glycolate) co-polyester copolymer for periodontal application,” Scientific Reports, 2018; 8(1): 7513.
17. M. Radunovic, M. De Colli, P. De Marco et al., “Graphene oxide enrichment of collagen membranes improves DPSCs differentiation and controls inflammation occurrence,” Journal of BiomedicalMaterials Research Part A, 2017; 105(8): 2312–2320.
18. N. Dubey, K. Ellepola, F. E. D. Decroix et al., “Graphene onto medical grade titanium: an atom-thick multimodal coating that promotes osteoblast maturation and inhibits biofilm formation from distinct species,” Nanotoxicology, 2018; 12(4): 274–289.
19. Compton OC, Nguyen ST. Graphene oxide, highly reduced graphene oxide, and graphene: Versatile building blocks for carbon-based materials. Small, 2010; 6: 711–72.