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Review

# Graphene for the development of the next-generation of biocomposites for dental and medical applications

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ABSTRACT

*Objective.* Graphene and its derivatives, graphene oxide (GO) and reduced graphene oxide (rGO), are 2D carbon-based materials with remarkable physical, chemical and biological properties. Graphene sheets have high specific surface area and mechanical strength. Moreover, they have been shown to influence the differentiation of stem cells and to improve properties of biomaterials.

*Methods.* Here, we present the recent achievements on the use of graphene and its derivatives to improve properties and enhance bioactivity of biomaterials. We also discuss the biosafety constraints to be solved to translate these carbonaceous materials to the clinic.

*Results.* Graphene and its derivatives can be functionalized and further modified with several bioactive molecules. They can be combined with several biomaterials used in regenerative and reconstructive dentistry and medicine. The resultant graphene-modified composites often present improved physico-mechanical properties and enhanced bioactivity. Moreover, graphene-modified composites are promising candidates to deliver growth factors, drugs and others bioactive compounds.

*Significance.* Graphene can improve the physical, chemical and mechanical properties of biomaterials. As it can be functionalized and combined with several biomolecules, graphene holds enormous potential to be used as drug carriers or substrates and scaffolds for cell-based tissue engineering strategies.



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## Contents



## 1. Introduction

The combination of two or more materials with different compositions, morphologies and properties can result in composites with tailored physical and chemical characteristics, and increased mechanical properties or bioactivity. Due to the enhanced capabilities, composites are widely used in dentistry and other biomedical areas as restorative materials, drug carriers, prosthetic parts and others [1,2].

Although composite materials can present several advantages that single-component materials fail to express, they may also present aspects that require further improvements. For instance, thermoplastic resin composites can be less toxic than the thermosetting ones but are prone to slow crack growth [3]. Also, ionomeric polymer–metal composites present large displacements when submitted to low applied voltage but are costly as their manufacturing depends on noble metals such as platinum and silver [4]. Ceramic–polymeric composites can be bioactive but may induce allergic reactions and present low mechanical properties [5]. Even with current advances, the development of new materials and methods to create the next generation of biocomposites with improved capabilities is of high interest.

In this context, emerges graphene emerges (Fig. 1). It is a single atomic sheet of conjugated $sp^2$ carbon atoms arranged in a honeycomb pattern with extremely high mechanical strength and modulus of elasticity. Moreover, graphene has unparalleled electronic properties and offers a large surface area that can be chemically functionalized [6–9]. Graphene has two derivatives, namely graphene oxide (GO) and reduced graphene oxide (rGO). GO can be prepared by oxidation of graphite. It presents several functional groups (e.g., hydroxyl, carboxyl and epoxy groups) that can be used to combine GO to several biomolecules and materials [10–12]. As such, GO is an interesting alternative to improve the mechanical properties and the bioactivity of biomaterials, or as carriers for biomolecules and drugs. The second derivative, rGO, can be produced by removing the oxygen-containing groups of GO with the recovery of a conjugated structure [13]. Although this process results in a material that resembles pristine graphene, oxygen-containing groups and defects in different proportions are found on the rGO surface [14].

Pristine graphene can be obtained via several routes (e.g. micro-mechanical exfoliation of graphite, chemical vapor deposition (CVD), epitaxial growth on SiC and others). The graphene produced by these methods presents an almost

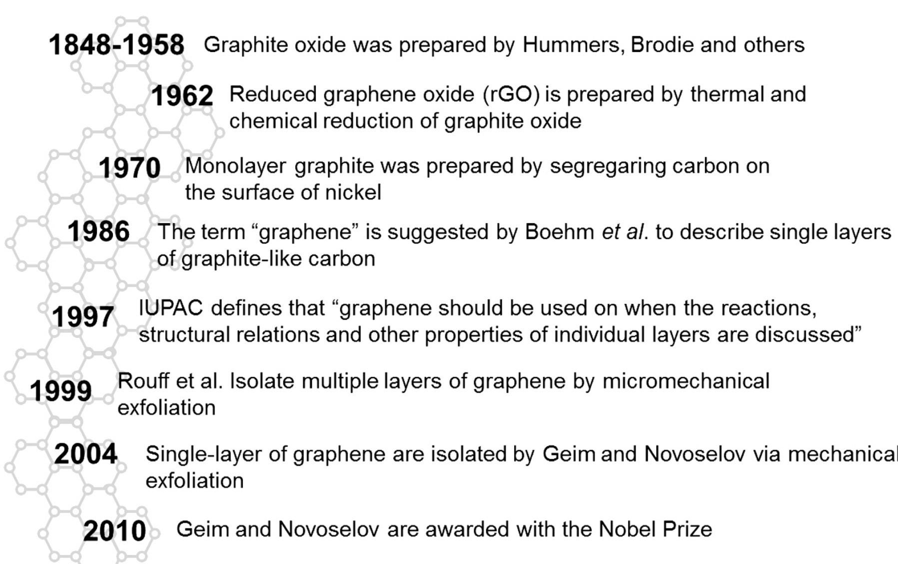


**Fig. 1 – Key milestones on graphene development.**