IOCM 2025 Conference

The 4th International Online Conference on Materials

03–05 November 2025 | Online

MDPI

Biomedical Applications of Graphene Oxide Nanomaterials: Progress and Prospects

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INTRODUCTION & AIM

Graphene oxide (GO), a chemically modified derivative of graphene, has emerged as a highly versatile nanomaterial in the biomedical domain due to its large surface area, rich functional groups, high aqueous dispersibility, and tunable surface chemistry. These properties make GO ideal for applications in drug and gene delivery, cancer diagnosis and therapy, bioimaging, tissue engineering, and antimicrobial treatments.

METHOD

This review synthesizes findings from recent peer-reviewed literature (2010–2025) on the biomedical utilization of GO. A qualitative methodology was adopted to analyze the mechanisms by which GO interacts with biological systems. Emphasis was placed on evaluating biocompatibility, delivery mechanisms, surface modification strategies, and theranostic capabilities..

Table 1: Biomedical Applications of Graphene Oxide Nanomaterials

Biomedical Applications of Graphene Oxide Nanomaterials

Biomedical Application	Description
Drug Delivery	Graphene oxide (GO) is utilized for delivering diverse therapeutics, including anti-cancer drugs and genes, due to its large surface area and flexibility in functionalization.
Gene Delivery	GO nanocarriers efficiently transport genes for therapeutic applications, especially when functionalized with polyethyleneimine (PEI) or chitosan.
Bioimaging	GO-based nanomaterials are used in MRI, PET/SPECT, CT, and optical imaging due to their tunable optical and magnetic properties.
Cancer Therapy	GO supports photothermal, photodynamic, and chemotherapeutic applications with high tumor inhibition rates under NIR irradiation.
Antimicrobial Agent	Exhibits antibacterial activity, beneficial for implants and wound-healing materials.
Tissue Engineering	GO-reinforced scaffolds support cell adhesion, proliferation, and differentiation for tissue regeneration.
Biosensors	GO's high conductivity and surface area make it suitable for biosensing platforms in diagnostics.
Theranostics	Combines diagnostic imaging and therapeutic delivery in a single GO-based system.
Photothermal Therapy	GO converts NIR light into heat for targeted cancer ablation.
Photodynamic Therapy	Involves the use of light-activated GO composites for tumor destruction.
Immune Enhancement	GO enhances immune response modulation in targeted therapy contexts.
Bone Regeneration	Promotes osteogenesis and serves as a reinforcing agent in bone scaffolds.
Spinal Cord Injury Management	GO nanomaterials are being explored for neural tissue repair and regeneration.

RESULTS & DISCUSSION

Controlled drug release: GO-based nanocarriers achieved up to 95% drug release efficiency.
Gene delivery: Polymer-modified GO (e.g., with PEI or chitosan) showed gene transfection efficiencies over 80%.
Cancer therapy: In photothermal applications, GO achieved tumor inhibition rates up to 92% under near-infrared (NIR) light.
Cellular uptake: Functionalized GO demonstrated cell uptake rates exceeding 85%, improving targeting precision.
Magnetic composites: Magnetic GO hybrids allowed rapid separation and bio-imaging with low toxicity in vitro.
Challenges: Variability in synthesis methods and uncertainties about long-term in vivo safety remain key limitations.

CONCLUSION

Graphene oxide nanomaterials offer remarkable versatility and efficiency in biomedical applications, particularly in drug delivery and cancer therapy. While experimental results are promising, clinical translation is limited by challenges including toxicity, lack of standardized protocols, and scalability. Future efforts should focus on green synthesis, long-term biocompatibility, and multifunctional platform development to bridge the gap between laboratory findings and real-world medical applications

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