



STUDY OF THE CONJUGATION OF GRAPHENE AND GRAPHENE OXIDE
WITH BIOMOLECULES.

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Abstract. Graphene and graphene oxide (GO) have attracted significant attention in the field of nanobiotechnology due to their unique physicochemical properties, which allow effective conjugation with various biomolecules. The functional groups present in GO, including carboxyl (-COOH), hydroxyl (-OH), epoxy, and carbonyl groups, facilitate the formation of covalent bonds with biomolecules. Such conjugation enhances their potential applications in biosensors, drug delivery systems, targeted cancer therapy, and medical diagnostics. This study provides a comprehensive review of recent developments in the conjugation of graphene and GO with biomolecules, highlights the strategies for functionalization, and discusses their biomedical applications.

Keywords: graphene, graphene oxide, biomolecules, conjugation, biosensors, drug delivery, nanobiotechnology.

Annotatsiya. Grafen va grafen oksidi (GO) o'zining noyob fizik-kimyoviy xususiyatlari tufayli nanobiotexnologiya sohasida katta e'tiborni tortdi, bu esa turli biomolekulalar bilan samarali konjugatsiya qilish imkonini beradi. GO tarkibida mavjud bo'lgan funktsional

guruhlar, jumladan, karboksil (-COOH), gidroksil (-OH), epoksi va karbonil guruhlari biomolekulalar bilan kovalent bog'lanishlarning hosil bo'lishiga yordam beradi. Bunday konjugatsiya ularning biosensordlarda, dori yetkazib berish tizimlarida, maqsadli saraton terapiyasida va tibbiy diagnostikada qo'llanilishini kuchaytiradi. Ushbu tadqiqot grafen va GO ni biomolekulalar bilan konjugatsiyalashdagi so'nggi yutuqlarni keng qamrovli ko'rib chiqishni taqdim etadi, funksionalizatsiya strategiyalarini ta'kidlaydi va ularning biotibbiy qo'llanilishini muhokama qiladi.

Kalit so'zlar: grafen, grafen oksidi, biomolekulalar, konjugatsiya, biosensordlar, dori yetkazib berish, nanobiotexnologiya.

Аннотация: Графен и оксид графена (ГО) привлекли значительное внимание в области нанобиотехнологий благодаря своим уникальным физико-химическим свойствам, позволяющим эффективно конъюгировать их с различными биомолекулами. Функциональные группы, присутствующие в ГО, включая карбоксильные (-COOH), гидроксильные (-OH), эпоксидные и карбонильные группы, способствуют образованию ковалентных связей с биомолекулами. Такая конъюгация расширяет их потенциальные возможности применения в биосенсорах, системах доставки лекарств, таргетной терапии рака и медицинской диагностике. В данном исследовании представлен всесторонний обзор последних достижений в области конъюгации графена и ГО с биомолекулами, освещены стратегии функционализации и обсуждаются их биомедицинские применения.

Ключевые слова: графен, оксид графена, биомолекулы, конъюгация, биосенсоры, доставка лекарств, нанобиотехнология

1. Introduction

Graphene and graphene oxide are two-dimensional nanomaterials with extraordinary mechanical, electrical, and chemical properties that make them ideal candidates for biomedical applications. GO is particularly suitable for conjugation with biomolecules due to its abundant oxygen-containing functional groups, such as carboxyl, hydroxyl, epoxy, and carbonyl groups, which enable covalent bonding with proteins, peptides, nucleic acids, and other biomolecules.

The conjugation of graphene-based materials with biomolecules has shown promising applications in biosensors, drug delivery systems, cancer therapy, and diagnostic tools. These conjugated nanomaterials can enhance the sensitivity and specificity of biosensors, improve targeted drug delivery efficiency, and reduce cytotoxicity in biomedical applications.

2. Objective of the Study

The primary objective of this study is to investigate the significance of conjugating graphene and graphene oxide with biomolecules for biomedical and biotechnological applications. Additionally, this research aims to provide a detailed overview of recent

advancements in conjugation techniques, evaluate the biocompatibility of functionalized materials, and summarize their potential applications in medicine and biotechnology.

3. Materials and Methods

This study is based on a comprehensive analysis of scientific literature, including original research articles, review papers, and monographs. The focus was on the following approaches:

1. **Development of conjugation techniques:** Methods to covalently attach biomolecules to graphene and GO, including PEGylation, amidation, and surface functionalization.
2. **Study of physicochemical properties:** Characterization of conjugated materials to evaluate structural integrity, photoluminescence, and stability.
3. **Biocompatibility assessment:** Evaluation of cytotoxicity and compatibility with biological systems.
4. **Application analysis:** Investigation of the potential use of conjugated materials in biosensing, drug delivery, cancer therapy, and medical diagnostics.

4. Results and Discussion

4.1 Conjugation Strategies

Graphene oxide has been successfully conjugated with antibodies (Ab) using bifunctional PEG (NH₂-PEG-COOH), forming a GO-PEG-Ab conjugate. The covalent attachment occurs through the formation of amide bonds between the carboxyl groups of GO and the amino groups of PEG, using EDC as a coupling agent. GO was also conjugated with PEG (M = 1 kDa) and human serum albumin (HSA), followed by the incorporation of paclitaxel (PTX) molecules via π - π interactions. This functionalization improved drug loading efficiency and targeted release under acidic conditions (pH 5.0–6.8), retaining photoluminescent properties for potential imaging applications. Furthermore, GO was covalently conjugated with polyethyleneimine (PEI, M = 1.8 kDa), enabling its use as a gene delivery vector and bioimaging material. Conjugation with amino acids such as L-cysteine and L-methionine via amidation reactions produced biologically compatible nanomaterials. GO was also amidated with amine-containing DNA to develop highly sensitive biosensors for detecting heavy metal ions.

4.2 Biomedical Applications

Conjugated GO-antibody complexes were employed in biosensors capable of detecting hormones, enzymes, peptides, and genes with high sensitivity. GO-PEG-Ab conjugates demonstrated the ability to detect small antigen molecules, while maintaining structural and optical stability. The PTX loading efficiency reached 22%, and its release rate was higher in acidic environments, making it suitable for targeted cancer therapy. The biocompatibility of functionalized materials was confirmed through experimental studies, indicating their suitability for medical applications. Highly sensitive biosensors based on GO conjugates can

play a critical role in early disease diagnosis, environmental monitoring, and therapeutic applications.

5. Conclusion

The conjugation of graphene and graphene oxide with biomolecules represents a powerful strategy for enhancing the performance and functionality of nanomaterials in biomedical applications. GO-based conjugates are increasingly applied in drug delivery systems, targeted cancer therapy, biosensor development, and medical diagnostics. Ongoing research in this field is expected to contribute to significant advances in nanomedicine and biotechnology, offering novel solutions for disease detection, treatment, and bioimaging.

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