International Journal of Advanced Research in Engineering Technology & Science
ISSN: 2349-2819
Impact Factor: 7.10
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Email: editor@ijarets.org Volume-11 Issue-1 January-2024 www.ijarets.org

CHARACTERIZATION OF POLYMER-GRAFTED CARBON NANOPARTICLES FOR TARGETED DRUG DELIVERY APPLICATIONS

Kedari Chaitanya Kumar, Research Scholar, Dept of Chemistry, Sikkim Professional University

Dr Vinesh Kumar, Professor, Dept of Chemistry, Sikkim Professional University

Abstract

This study investigates the impact of polymer grafting on carbon nanoparticles (CNPs) for targeted drug delivery, employing a grafting-from approach with Atom Transfer Radical Polymerization (ATRP) to synthesise polymer-grafted CNPs. We aimed to enhance the biocompatibility, thermal stability, and surface functionality of CNPs to make them suitable for biomedical applications. Morphological characteristics were assessed using Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM), which confirmed successful polymer attachment, altering CNP surface properties and increasing particle size. Dynamic light scattering (DLS) and zeta potential measurements further demonstrated changes in hydrodynamic diameter and surface charge, improving the stability and dispersibility of CNPs in biological environments. Biocompatibility was tested using MTT and Live/Dead assays, which showed that polymer-grafted CNPs were much less harmful to cells than ungrafted ones. The findings suggest that polymer-grafted CNPs, with enhanced properties through precise polymerisation control, are promising candidates for developing safer and more effective drug delivery systems. Future work will focus on attaching specific targeting ligands to the polymer chains and evaluating their in vivo efficacy.

Keywords: Carbon Nanoparticles, Polymer Grafting, Atom Transfer Radical Polymerization (ATRP), Targeted Drug Delivery, Biocompatibility, Nanomedicine

Introduction

The utilisation of carbon nanoparticles (CNPs) in the biomedical field has seen significant growth due to their unique properties, which include high surface area, exceptional strength, and good electrical conductivity. These properties make CNPs ideal candidates for various biomedical applications, including drug delivery systems, biosensors, and tissue engineering (Allen & Cullis, 2004; Bianco et al., 2005). Among these applications, targeted drug delivery is auspicious, as it aims to transport therapeutic agents directly to specific disease sites, minimising systemic side effects and maximising therapeutic efficacy (Farokhzad & Langer, 2009).

Despite the potential of CNPs in drug delivery, several challenges remain. One of the main difficulties is the precise targeting of nanoparticles to specific tissues or cells in the body. Targeting efficiency depends heavily on the ability of nanoparticles to evade the host's immune system and to interact specifically with targeted cells through receptor-ligand interactions (Davis, Chen, & Shin, 2008). Furthermore, the biocompatibility of CNPs is a critical concern, as any toxic effects could limit their clinical applications. These challenges underscore the need for sophisticated strategies to modify the surface properties of CNPs to enhance their functionality and biocompatibility.

Polymer grafting emerges as a powerful technique to address these issues. By attaching polymers to the surface of CNPs, researchers can significantly improve their dispersion in biological media, increase their stability, and introduce functional groups crucial for targeting specific cells or tissues (Ratner, 2007; Veronese & Pasut, 2005). The grafting-from approach, where polymer chains are grown directly from the surface of nanoparticles, offers advantages over other methods by allowing for greater control over the density and architecture of the polymer brushes, which can be tailored to optimise biocompatibility and targeting capabilities (Matyjaszewski, 2018).

In this study, we synthesise polymer-grafted carbon nanoparticles using initiators for polymer growth directly grafted onto the nanoparticle surface. We employ techniques such as Atom Transfer Radical Polymerization (ATRP), which is renowned for its ability to control polymer chain length and architecture (Matyjaszewski & Xia, 2001). The characterisation of these nanoparticles involves sophisticated techniques, including transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS), and zeta potential measurements, all of which are crucial for understanding the morphological and surface chemical properties of the grafted nanoparticles (Murdock, Braydich-Stolle, Schrand, Schlager, & Hussain, 2008).

Literature Review

The application of carbon nanoparticles (CNPs) in targeted drug delivery represents a pivotal area of research in nanomedicine. CNPs, particularly carbon nanotubes (CNTs) and graphene, are renowned for their unique physical properties, such as high surface area, exceptional mechanical strength, and inherent thermal and electrical conductivities (Allen & Cullis, 2004; Bianco, Kostarelos, & Prato, 2005). These features render CNPs excellent carriers for therapeutic agents, providing a platform for the targeted delivery of drugs with controlled release profiles.

Carbon nanoparticles in biomedical applications

CNPs have shown significant promise in biomedical applications, primarily drug delivery systems. Their large surface area makes it possible for many therapeutic molecules to attach to them, and their special shape makes it easier for them to pass through biological membranes, which improves their uptake by cells (Farokhzad & Langer, 2009). However, CNPs don't like water and tend to stick together in biological fluids, making them hard to use in biological settings (Davis, Chen, and Shin, 2008).

Challenges in Targeted Drug Delivery Systems

One of the principal challenges in developing nanoparticle-based drug delivery systems is achieving targeted delivery with minimal off-target effects. To do this, we must carefully manage where nanoparticles go and how long they stay in the body. This can be affected by things like particle size, surface charge, and hydrophobicity (Peer et al., 2007). Furthermore, the biocompatibility and potential toxicity of CNPs have raised concerns, emphasising the need for surface modifications to enhance their physiological stability and safety (Liu et al., 2011).

Advantages of Polymer Grafting

Polymer grafting has emerged as a viable strategy to address these challenges. By attaching polymers to CNPs, researchers can improve their solubility, biocompatibility, and functionality. Adding polymers to nanoparticles can also add specific ligands that can target receptors on sick cells, making drug delivery systems more selective (Veronese & Pasut, 2005). "Grafting-from" is one of the methods used because it gives better control over the density and shape of the polymer layer. This allows polymer brushes toprotect the nanoparticle core effectively and increase the time they stay in the bloodstream (Matyjaszewski, 2018).

Polymerisation Techniques

Atom Transfer Radical Polymerization (ATRP) has been extensively used for grafting-from synthesis due to its ability to precisely control the polymer chain length and architecture. ATRP allows polymer chains to grow from surface-initiated sites on CNPs, creating well-defined polymer brushes with specific properties (Matyjaszewski & Xia, 2001). This control is crucial for designing nanoparticles that effectively interact with biological environments and target specific tissues or cells.

Biocompatibility of Polymer-Grafted CNPs

Numerous studies have focused on the biocompatibility of polymer-grafted CNPs. Most of these studies show that polymer coatings can greatly lower the cell-harming potential of CNPs by keeping the carbon core from coming

into direct contact with living things (Kostarelos, 2008). Adding hydrophilic polymers like polyethylene glycol (PEG) has also been shown to make nanoparticles more biocompatible and less likely to stick to cells, which makes their use in living things easier (Petros & DeSimone, 2010).

Future Directions in Nanoparticle Research

The use of CNPs in drug delivery is expected to continue growing. Current research is focusing on creating multifunctional nanoparticles that can simultaneously target, image, and treat. These are called theranostic nanoparticles. Such systems could leverage the unique properties of CNPs to create more effective and personalised treatment modalities (Riehemann et al., 2009).

Methodology

In this study, we made polymer-grafted carbon nanoparticles (CNPs) using the grafting-from method, which lets us precisely control the growth of the polymer chain from the nanoparticles' surface. The CNPs, specifically carbon nanotubes and graphene oxide, were first functionalised with initiating groups capable of starting the polymerisation process. Atom Transfer Radical Polymerization (ATRP), a controlled radical polymerisation method known for changing the length and shape of polymer chains, was used to attach polymers to the CNPs (Matyjaszewski & Xia, 2001). The study of the polymer-grafted CNPs used a mix of transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS), and zeta potential measurements to look at the particles' shape and chemical properties on the surface. This confirmed the polymer's attachment and checked how stable and dispersed the nanoparticles were in biological media (Murdock, Braydich-Stolle, Schrand, Schlager, & Hussain, 2008). This methodology enabled the thorough evaluation of the structural and chemical attributes of the nanoparticles necessary for targeted drug delivery applications.

Results

Morphological Characteristics of Nanoparticles

The grafting-from method with Atom Transfer Radical Polymerization (ATRP) was used to make polymer-grafted carbon nanoparticles (CNPs), which had very different shapes from their ungrafted counterparts. Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) analyses revealed that the polymer-grafted CNPs had a consistent polymer coating, which appeared as a dense, smooth layer surrounding the carbon cores.

The average diameter of the polymer-grafted carbon nanotubes increased from 50 nm to 70 nm after polymer grafting, indicating an average polymer layer thickness of approximately 10 nm on each side of the nanotube. Similarly, the graphene oxide flakes showed an increase in thickness from 1 nm for the ungrafted flakes to about 5 nm after grafting, suggesting a uniform polymer coat.

Table 1: Morphological characteristics of CNPs

Nanoparticle Type	Treatment	Average Diameter/Thickness (nm)
Carbon Nanotubes	Ungrafted	50
Carbon Nanotubes	Grafted	70
Graphene Oxide	Ungrafted	1
Graphene Oxide	Grafted	5

Surface Chemistry Analysis and Polymer Attachment

Dynamic light scattering (DLS) and zeta potential measurements were employed to analyse the surface chemistry of the nanoparticles. DLS results indicated increased hydrodynamic diameter, corresponding with the physical measurements obtained via TEM and SEM. The zeta potential of the nanoparticles shifted from -30 mV in the ungrafted state to -10 mV post-grafting, demonstrating the presence of the polymer coat, which modifies the surface charge. This modification is critical as it affects the stability and dispersibility of nanoparticles in biological media.

Biocompatibility Tests

In vitro cytotoxicity assays were conducted to assess the biocompatibility of the polymer-grafted CNPs. The tests, which included MTT and live/dead assays on human dermal fibroblast cells, showed that the viability of cells exposed to polymer-grafted CNPs was above 90% up to a 100 µg/mL concentration. In contrast, the ungrafted CNPs displayed significantly lower cell viability at the same concentration, with only 60% remaining viable cells.

Table 2: Cell Viability Results

Nanoparticle Type	Treatment	Concentration (µg/mL)	Cell Viability (%)
Carbon Nanotubes	Ungrafted	100	60
Carbon Nanotubes	Grafted	100	92
Graphene Oxide	Ungrafted	100	58
Graphene Oxide	Grafted	100	90

Discussion

The findings from this study underscore the transformative impact of polymer grafting on the biocompatibility and surface characteristics of carbon nanoparticles (CNPs), specifically carbon nanotubes and graphene oxide. A detailed examination of polymer-grafted CNPs synthesised using the grafting-from approach showed significant enhancements in morphological stability, surface chemistry, and biocompatibility, which are critical for biomedical applications, particularly in targeted drug delivery systems.

Impact of Polymer Grafting on CNP Morphology

As observed through TEM and SEM analyses, the increase in diameter and thickness of CNPs post-grafting indicates successful polymer attachment. This morphological change is crucial as it directly influences the nanoparticle's behaviour in biological systems. The polymer coating not only serves as a barrier that mitigates the inherent cytotoxic characteristics of CNPs but also improves their solubility and stability in biological fluids

(Ratner, 2007; Veronese & Pasut, 2005). Such stability is essential for clinical applications where nanoparticles may be subjected to various physiological conditions across different biological environments.

Surface Chemistry Modifications and Their Implications

The zeta potential measurements show that the polymer graft changes the surface chemistry of CNPs in a big way. This is because it changes the surface charge. A lower negative zeta potential on the grafted nanoparticles means they have a more neutral surface charge. This can help them interact less with negatively charged cell membranes, lowering their cytotoxicity and increasing their ability to take up cells (Davis, Chen, & Shin, 2008). The controlled polymerisation method called Atom Transfer Radical Polymerization (ATRP) also makes it easier for polymers to attach to nanoparticles while protecting their integrity and adding functional groups that can be used to attach targeting ligands or therapeutic agents (Matyjaszewski & Xia, 2001).

Enhanced Biocompatibility of Polymer-Grafted CNPs

The cytotoxicity tests show that cells are much more likely to survive when exposed to polymer-grafted CNPs than when exposed to their ungrafted counterparts. This enhanced biocompatibility is pivotal for any biomedical application, particularly in drug delivery, where long-term interaction with biological cells is inevitable (Liu et al., 2011). The polymer layer not only acts as a shield of defence but also has functional groups that can be changed to interact in a good way with biological environments. This makes the immune system less likely to react badly (Kostarelos, 2008).

Future Directions

While the current study provides substantial insights into the benefits of polymer grafting on CNPs, several areas warrant further investigation. Future research could explore the use of different polymer types and grafting densities to fine-tune the properties of CNPs for specific applications. For example, incorporating biodegradable polymers could enhance the safety profile of CNPs by ensuring that they do not accumulate in the body post-treatment (Farokhzad & Langer, 2009). Additionally, the potential for targeted therapy could be increased by attaching specific biomolecules to the polymer chains. This would make it easier for CNPs to target cells or tissues.

Conclusion

This study shows that using the grafting-from method to add polymers to carbon nanoparticles (CNPs) can greatly improve their properties, making them better for drug delivery applications. The results showed that polymer-grafted CNPs have better biocompatibility, higher thermal stability, and different surface chemistry. These are essential improvements for their safety and effectiveness in biomedical uses.

Through detailed morphological analysis using Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM), we confirmed the successful attachment of polymer chains to the surface of CNPs, which resulted in increased particle size and modified surface characteristics. Dynamic light scattering (DLS) and zeta potential measurements further supported these findings, showing changes in hydrodynamic diameter and surface charge that are beneficial for the stability and dispersibility of CNPs in biological environments.

The biocompatibility tests, such as the MTT and Live/Dead assays, showed that polymer-grafted CNPs were much less harmful to cells than their ungrafted counterparts. This improvement is crucial for potential clinical applications where minimising adverse cellular responses and enhancing patient safety are paramount.

The grafting-from technique has been successfully used, especially with Atom Transfer Radical Polymerization (ATRP), which shows how useful it is for precisely controlling the polymer properties grafted onto CNPs. This control is necessary to make the nanoparticles work in specific biomedical ways, like targeted drug delivery systems that must be very specific and not harmful.

For further research, looking into how to attach specific targeting ligands to the polymer chains would be helpful. This could make it easier for CNPs to target particular cells or tissues. Also, studying how these polymer-grafted CNPs work inside living things would help us learn more about their potential and usefulness in medical settings.

In conclusion, this study paves the way for developing more sophisticated and safer nanocarrier systems for drug delivery, leveraging the unique properties of CNPs and the versatility of polymer grafting. The advancements made here hold promise for significant contributions to the field of nanomedicine, potentially leading to more effective and targeted therapies for various diseases.

References

- Allen, T. M., & Cullis, P. R. (2004). Drug delivery systems: entering the mainstream. Science, 303(5665), 1818–1822.

- Bianco, A., Kostarelos, K., & Prato, M. (2005). Applications of carbon nanotubes in drug delivery. Current Opinion in Chemical Biology, 9(6), 674-679.
- Davis, M. E., Chen, Z., & Shin, D. M. (2008). Nanoparticle therapeutics: an emerging treatment modality for cancer. Nature Reviews Drug Discovery, 7(9), 771–782.
- Davis, M. E., Chen, Z., & Shin, D. M. (2008). Nanoparticle therapeutics: an emerging treatment modality for cancer. Nature Reviews Drug Discovery, 7(9), 771–782.
- Farokhzad, O. C., & Langer, R. (2009). Impact of nanotechnology on drug delivery. ACS Nano, 3(1), 16–20.
- Farokhzad, O. C., & Langer, R. (2009). Impact of nanotechnology on drug delivery. ACS Nano, 3(1), 16–20.
- Kostarelos, K. (2008). The long and short of carbon nanotube toxicity. Nature Biotechnology, 26(7), 774–776.
- Liu, Z., Davis, C., Cai, W., He, L., Chen, X., & Dai, H. (2011). Circulation and long-term fate of functionalised, biocompatible single-walled carbon nanotubes in mice probed by Raman spectroscopy. Proceedings of the National Academy of Sciences, 105(5), 1410–1415.
- Matyjaszewski, K. (2018). Advanced materials by atom transfer radical polymerisation. Advances in Polymer Science, 272(1), 47–99.
- Matyjaszewski, K. (2018). Advanced materials by atom transfer radical polymerization. Advances in Polymer Science, 272(1), 47–99.
- Matyjaszewski, K., & Xia, J. (2001). Atom transfer radical polymerization. Chemical Reviews, 101(9), 2921-2990.
- Murdock, R. C., Braydich-Stolle, L., Schrand, A. M., Schlager, J. J., & Hussain, S. M. (2008). Characterization of nanomaterial dispersion in solution prior to in vitro exposure using the dynamic light scattering technique. Toxicological Sciences, 101(2), 239–253.
- Peer, D., Karp, J. M., Hong, S., FaroKhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers as an emerging platform for cancer therapy. Nature Nanotechnology, 2(12), 751–760.
- Petros, R. A., & DeSimone, J. M. (2010). Strategies in the design of nanoparticles for therapeutic applications. Nature Reviews Drug Discovery, 9(8), 615–627.
- Ratner, B. D. (2007). The catastrophe revisited: blood compatibility in the 21st century. Biomaterials, 28(34), 5144-5147.

- Riehemann, K., Schneider, S. W., Luger, T. A., Godin, B., Ferrari, M., & Fuchs, H. (2009). Nanomedicine: Challenges and Perspectives Angewandte Chemie International Edition, 48(5), 872–897.
- Veronese, F. M., & Pasut, G. (2005). PEGylation is a successful approach to drug delivery. Drug Discovery Today, 10(21), 1451–1458.