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International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Nanotechnology of Modern Pharmaceutical Tax: Progress and Application

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ABSTRACT :

Nanotechnology has revolutionized the field of modern pharmaceuticals, offering advanced systems for targeted drug delivery and treatment efficacy. This review explores key developments in nanostructures such as liposomes, dendrimers, polymeric nanoparticles, and solid lipid nanoparticles (SLNs). These nanocarriers present significant advantages including enhanced bioavailability, targeted action, and reduced toxicity. However, challenges related to clinical translation, toxicity, and regulatory approval remain. This paper aims to summarize recent advances, discuss critical limitations, and evaluate the therapeutic potential of nanotechnology in drug delivery systems.

1. Introduction

The integration of nanotechnology in pharmaceutical sciences represents a groundbreaking shift in drug design and delivery. Traditional drug delivery methods often face issues such as poor solubility, rapid metabolism, and nonspecific distribution, resulting in suboptimal therapeutic outcomes and increased side effects. Nanocarriers offer innovative strategies to overcome these challenges, providing platforms capable of delivering drugs precisely to the site of action while minimizing systemic toxicity. The use of nanotechnology in medicine enhances diagnosis, monitoring, and treatment, with increasing application in oncology, infectious diseases, and chronic conditions.

2. Literature Review

Research in the past two decades has identified several classes of nanostructures with pharmaceutical potential:

- Liposomes: Spherical vesicles with a phospholipid bilayer capable of carrying both hydrophilic and hydrophobic drugs. They are biocompatible and enhance drug solubility and circulation time.

- Dendrimers: Synthetic, tree-like molecules that offer high drug-loading capacity, precise control over size and surface functionality, and the ability to target specific cells or tissues.

- Polymeric Nanoparticles: Made from biodegradable polymers like PLGA or PEG, these offer controlled and sustained drug release, with applications in cancer therapy and vaccine delivery.

- Solid Lipid Nanoparticles (SLNs): These combine the advantages of liposomes and polymeric nanoparticles, offering stability, biocompatibility, and controlled drug release.

Numerous studies have demonstrated the efficacy of these nanocarriers in preclinical and early clinical settings. However, scaling up production and ensuring long-term safety remains a challenge.

3. Methodology

This review is based on a comprehensive analysis of peer-reviewed journal articles, clinical trial reports, and regulatory documents published over the past 10 years. Databases such as PubMed, ScienceDirect, and Web of Science were used to extract relevant information. Keywords included "nanotechnology drug delivery," "liposomes," "dendrimers," "polymeric nanoparticles," and "solid lipid nanoparticles." Inclusion criteria prioritized studies that reported experimental results, clinical outcomes, and discussed translational barriers.

4. Discussion

Nanocarriers have shown the ability to improve pharmacokinetics and pharmacodynamics of drugs. Their ability to bypass biological barriers and release drugs at the site of disease has led to better patient outcomes, particularly in cancer treatments. For example, liposomal doxorubicin (Doxil) is an FDA-approved nanodrug that has demonstrated reduced cardiotoxicity compared to free doxorubicin.

The targeted delivery capability is often achieved by attaching ligands or antibodies to the nanocarrier surface, directing the payload to specific cells or tissues. This minimizes damage to healthy tissues and maximizes drug efficiency. Furthermore, nanocarriers can be engineered to respond to internal stimuli (pH, enzymes) or external triggers (heat, light), allowing controlled and site-specific drug release.

However, nanodrug development faces challenges:

- Toxicity: Nanoparticles may induce unforeseen toxicological responses due to their small size and surface reactivity.
- Regulatory Hurdles: A lack of standardized testing methods complicates regulatory approval.
- Scalability and Cost: Manufacturing consistent and stable nanocarrier formulations at large scale remains a technological and economic barrier.

5. Conclusion

Nanotechnology holds immense promise in pharmaceutical sciences by improving drug delivery systems. The benefits of enhanced bioavailability, targeted delivery, and controlled release make nanocarriers an invaluable tool in modern medicine. Nonetheless, successful clinical application requires addressing the current limitations in toxicity, scalability, and regulatory frameworks. Continued interdisciplinary research is essential to unlock the full potential of nanomedicine and facilitate its integration into mainstream therapeutic strategies.

6. REFERENCES

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