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Application of nanomaterials for drug delivery

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Abstract. One of the most important trends in recent years has been the use of nanomaterials for drug delivery. Drug treatment and application have been considerably aided by drug delivery techniques. The relentless search of cutting-edge delivery systems and methods is essential to the quick development of the medication therapy profession. The development of nanomedicines, or drug-delivery particles of 1-100 nm in size manufactured from medications and excipients, is the result of the fusion of nanotechnology and pharmacy. The primary drug delivery techniques currently in use, the nanomaterials that can be used, and the actual applications of nano-delivery are briefly discussed in this research. The topic of this research is increasing the likelihood and precision of multi-armed bandit attacks. The purpose of this research is to improve understanding of the nanodrug delivery framework. The prevailing trends in the area of drug delivery is further analyzed, where several researches have demonstrated that nanomaterials are one of the good options for drug delivery. The reported research shows several applications of drug delivery in different research areas to demonstrate that nano-delivery holds good promise for use and development. In addition, this research helps one to understand, review and enhance the basic application and development framework of nanodrug delivery.

Keywords: nanomaterials, drug delivery, disease treatment.

1. Introduction

Drug delivery systems are pieces of technology that regulate how medications are distributed within an organism to deliver medications to the correct location at the appropriate time, while also enhancing on-target delivery, minimizing off-target effects, and enhancing patient compliance. One of the useful drug delivery technologies is the delivery of drugs using nanomaterials. There are many different ways to do this. In terms of stability, surface characteristics, and size, using nanomaterials has advantages. For instance, by adjusting the size of nanomedicines to improve intra-tumour penetration.

Drug delivery methods using nanoparticles can lessen systemic toxicity. Nanomaterials are extremely tiny pieces of solid matter, with their smallest unit size being between 1 and 100 nm. Small grains, fewer atoms per grain, and a high concentration of grain boundary surface effects are characteristics of nanomaterials. As a result, when compared to traditional macroscopic materials, nanoparticles have exceptional optical, electrical, and magnetic characteristics.

Numerous scholars have done substantial research in the field of nanomaterials with a focus on drug delivery [1]. Given that the body provides a variety of biological “barriers” that drug nanocarriers

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(NCs) would meet, it is essential to have a comprehensive knowledge of how nanomaterials interact with biological systems for any such model characteristics to be successful in vivo. Even if many nanomaterials are powerful and have elegant designs, this is still the case. The use of nanoparticles in medication delivery has a history. The various biological obstacles that NCs must get over to fulfil their intended function as therapeutic agents were described in 2013 [1]. Zhao et al. highlighted the most recent advancements in drug delivery systems (DDSs) using carbon nanomaterials in 2017 [2], including immediate/continuous and controlled/targeted DDSs. Jacob et al. in 2017 presented significant developments in nanomaterial-based drug delivery techniques using biopolymers such as proteins and polysaccharides [3]. The harsh acidic environment of endolysosomes, where pharmaceuticals must escape in tissues or cellular targets and where biomolecular medications such as proteins, and oligonucleotides might be inactivated or destroyed. These researches received much attention in these investigations. Even diseased cells and nuclear membranes can develop a variety of drug resistance mechanisms.

This research will discuss the use of nanomaterial-based drug delivery in a variety of different biomedical fields, such as ocular drug therapy, oncology drug delivery and vaccines. It will also refer to the five classes of nanoparticle drug delivery processes that currently dominate based on platform content: polymeric nanoparticles, inorganic nanoparticles, viral nanoparticles, lipid-based nanoparticles, and nanoparticle albumin-binding technologies. The disadvantage of nanomaterials is that their nanotoxicity and biodistribution cannot be avoided.

2. Classification of drug delivery systems

Drug delivery systems are a well-established and well-researched area of research, and there are currently three main established categories of drug delivery systems, including liposomal drugs, inhalation therapy, and brain drug delivery-multiple ways of overcoming the blood-brain barrier.

2.1. Liposome drug

Particularly appealing for medication delivery are liposomes. On the one hand, through preferential extravasation from the tumour vasculature, the “increased permeability and retention” effect can be used to lower cardiac toxicity. Furthermore, lipids are crucial parts of cell membranes, are extremely biocompatible, do not have issues with biodegradation, and are simple to add hydrophilic and hydrophobic molecules to. Fluid membranes are able to support dynamic ligand reorganization because liposomes are malleable and easily deformed. To create supported lipid monolayers or bilayers, lipids may also encapsulate inorganic and polymeric nanoparticles. Properties including lipid structural domain creation, mobility, leakage, and fusion have all been employed for drug administration.

2.2. Inhalation therapy

Pulmonary drug delivery research has advanced significantly over the past few years, and it currently offers many advantages over other drug delivery techniques for the treatment of respiratory illnesses. Inhalation therapy allows for the direct local distribution of drugs to the lungs, where they work on the respiratory mucosa and/or alveoli. This is accomplished by using aerosols, dry powders, or nebulized fluids. Since the medication is inhaled, it acts directly on the target, increasing the local concentration and efficacy. The rebuildable controlled-release formulation further increases patient comfort and treatment compliance. Aerosol formulations are effective, simple to use, and reasonably priced. By altering delivery technology and formulation science, the treatment state of the illness can be improved.

2.3. Brain drug delivery

It might be difficult to treat illnesses of the central nervous system such encephalitis, myelitis, and vascular lesions. And the blood-brain barrier (BBB), which consists of physiological, metabolic, and biochemical barriers, frequently prevents the medication molecules used to treat various disorders

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from crossing. Patients with concurrent brain illnesses now have a dismal prognosis, but upcoming advancements in medication delivery technologies may improve their care.

3. Nanomaterials for drug delivery

Nanomaterials are used in a wide range of drug delivering systems and the following is a description of nanomaterials that can be used for drug delivery. Here, this research mainly introduces several common nanoparticles, including polymeric nanoparticles, inorganic nanoparticles, viral nanoparticles, lipid-based nanoparticles and albumin nanoparticles.

3.1. Polymeric nanoparticles

The medicinal ingredient is enclosed in a PNP core that is made of polymeric nanoparticles (PNPs), which are frequently spontaneously complex self-assembled structures in the form of nanospheres or nanocapsules. PNPs are a crucial technique for increasing a drug's bioavailability or site-specific delivery. Polymeric carriers are among the available carrier systems that are simple to synthesis, affordable, biocompatible, biodegradable, non-immunogenic, non-toxic, and water-soluble. Due to their adaptability, they are the perfect choice for a range of particular drug delivery systems. PNPs are easily integrated with other processes, such tissue engineering, for drug delivery. Additionally, they give volatile active components stability and a longer duration of activity while delivering active ingredients to target tissues or organs at specified quantities. Thus, depending on the choice of polymer and the ability to modulate PNP drug release, PNPs could be considered ideal candidates for vaccine delivery, cancer therapy and targeted antibiotic delivery. PNPs have contributed significantly to drug delivery over the last three decades. polymeric nanoparticles, physicochemical characteristics, preparation techniques, therapeutic implications, proprietary technologies for nanoparticles and future possibilities in the field of ocular drug delivery were discussed by Nagarwal et al. in 2009 [4]. Later in 2011, Abdel-Mottaleb et al. investigated the behavior of LNCs as a transdermal drug delivery system using ibuprofen as a model drug, which was later refined to further refine this potential therapeutic approach [5].

3.2. Inorganic nanoparticles

Inorganic nanoparticles are more innocuous, more hydrophilic, biocompatible and very stable than organic compounds, so the use of inorganic nanoparticles for drug delivery is becoming more common over time. Drug delivery using nanoparticles is one of the principals uses of nanotechnology. This field of study is flourishing and offers a demanding environment for researchers. The utilization of inorganic nanoparticles for medication delivery and associated research is one of the emerging challenges. Finding medications and/or delivery methods that increase effectiveness at the desired site of action while lowering toxicity to healthy tissues is primary goal in drug development. Yu et al. reported the large-scale synthesis of monodisperse and molecular organic-inorganic hybrid MON with framework-bound physiologically active thioether bonds and controlled nanostructure, composition, and morphology later in 2018 [6]. This work served as a material foundation for investigating organosilicon nanosystems for multifunctional biomedical applications, as shown in Figure 1.

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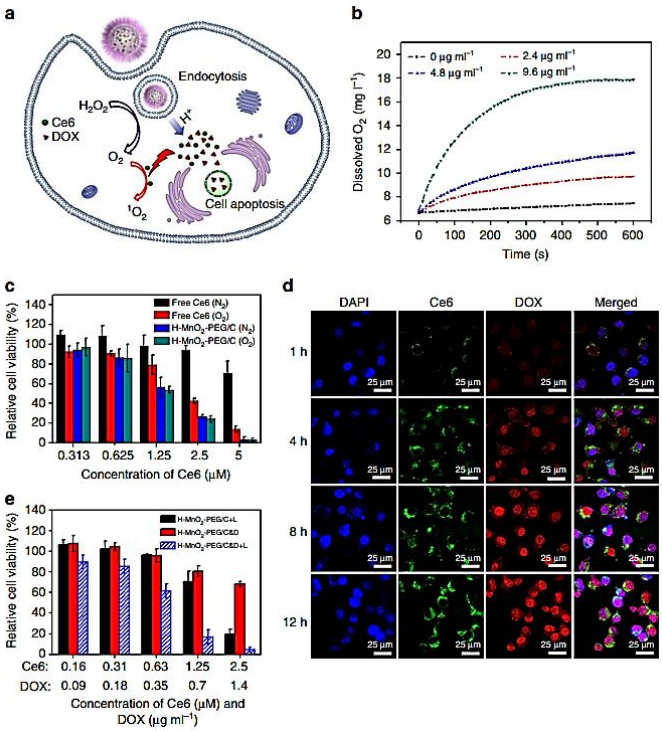


Figure 1. In vitro experimental results with the prepared materials [6].

3.3. Viral nanoparticles

Viruses may qualify as natural nanomaterials within the confines of the nanoscale scale and have been employed as scaffolds for the formation of metallized or mineralized structures, resulting in metallized or mineralized building blocks. Viruses can also serve as nanocages to contain materials. The use of viral nanoparticles and their genome-free counterparts, virus-like particles (VLPs), for the delivery of drugs is quickly developing. By chemically or genetically binding targeting ligands, viral nanoparticles can target specific tissues while encapsulating a wide variety of active substances. Large-scale fermentation or molecular farming are used to create biocompatible, biodegradable viral nanoparticles. VLPs can consequently be employed in a variety of medication delivery applications.

3.4. Lipid-based nanoparticles

Drug delivery utilizes a variety of lipid-based nanoparticles (LBNPs), including liposomes, solid lipid nanoparticles (SLNs), and nanostructured lipid carriers (NLCs). These nanoparticles have very little to no toxicity, can carry both hydrophobic and hydrophilic molecules, and can prolong the half-life and controlled release of drugs to extend the duration of pharmacological activity. Chemical alterations to lipid nanosystems can improve the solubility of the nanoparticles. Additionally, to promote medication release in acidic conditions, they might be manufactured in pH-sensitive formulations. An overview of lipid nanoparticles as cutaneous drug delivery systems is given by Campani et al. in 2018 along with a review of lipid synthesizing nanoparticles, in vivo experiments characterization methods, and their detection [7]. In the last five years, most of the research and development has been dedicated to creating therapeutically effective, side-effect-free alternatives to drug molecules by creating suitable drug delivery systems. In 2020, Niora et al. will compare different commonly used lipid-based nanoparticles using 3D tumour spheres and light-sheet fluorescence microscopy [8], as shown in Figure 2.

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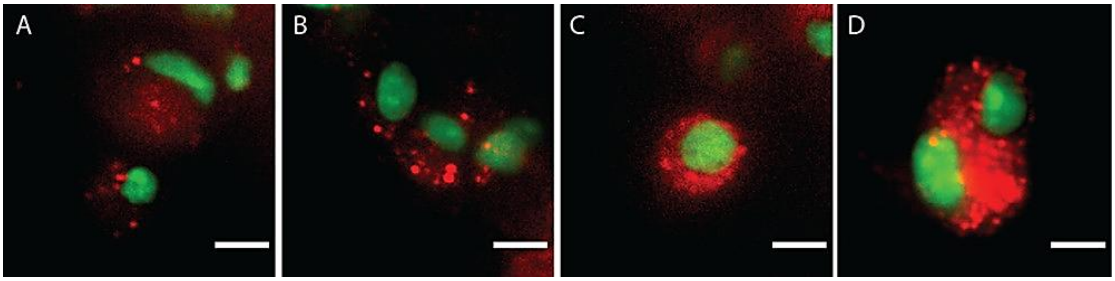


Figure 2. Images of cellular uptake of NPs [8].

3.5. Albumin nanoparticles

Albumin nanoparticles are among the most important drug delivery systems for therapeutic drugs, especially those used to treat malignant tumors. Due to their beneficial characteristics and safety, protein-based nanocarriers are utilized. Albumin has a high affinity for both hydrophobic and hydrophilic medicines, and surface modification is a possibility. Additionally, because albumin contains a wealth of carboxyl and amino groups, some ligands, including monoclonal antibodies, folic acid, transferrin, and peptides, can attach to the surface of albumin nanoparticles and help medications be actively targeted to the site of action. Because albumin naturally targets cells via gp60 and SPARC-mediated receptor endocytosis, albumin-based nanoparticles are an efficient drug delivery strategy. Albumin nanosystems and stimulus-responsive drug release have both been linked. Furthermore, albumin nanocarriers increase the stability of other medicinal products, such as nucleic acids, enabling systemic delivery. Increased permeability and retention effects, as well as binding to secreted proteins that are acidic and cysteine-rich and found in the tumor extracellular matrix, all contribute to the accumulation of albumin-bound medicines in the tumor mesenchyme. A lot of biotechnology and pharmaceutical businesses are interested in albumin due to its economic success.

4. Application of nanomaterial drug delivery

There are many transport barriers in the complex process from the site of introduction to the site of molecular action, such as rapid filtration by the kidney and clearance by the reticuloendothelial system (RES), which nanomaterials can help to overcome.

4.1. Ocular drug therapy

Effective drug delivery to the eye remains a challenging task for drug scientists due to the various anatomical barriers and clearance mechanisms that exist within the eye. This is because there are a variety of abnormal states and problems with clearance mechanisms within the eye. This is the traditional distribution system as there are other situations where drugs are used for the task. Injection into the vitreous cavity and system may lead to biohazards in the eye.

The ideal ophthalmic drug delivery system contains the following three properties: the controlled slow release, the prolonged targeting and retention in diseased tissues and the reduction or elimination of side effects arising from these direct drug delivery methods. Therefore, an intra-ocular drug delivery system based on nanocarriers is considered to be the most suitable means of meeting the ideal ocular drug delivery system. The cornea permeability of such nanomaterial drugs can be improved by topical drug delivery. In a similar way, the interaction with the outer mucosa of the corneal surface is enhanced due to the high surface area to volume ratio of the nanocarriers, thus extending the duration of drug retention. Topical drugs The field of ophthalmic drug delivery has been greatly influenced by advertising in the last decade. Advances in technology, particularly the development of nanostructured drug carriers. Drug-encapsulated nanoparticles can improve the overall performance of ocular drug delivery systems, enhance drug delivery to the ocular surface and offer new possibilities for drug delivery systems [9].

The usage of a wide range of nanomaterials has received more and more intention since several studies have demonstrated that drug carriers such hydrogels, lysosomes, and CDs are utilized to

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increase the bioavailability of different therapeutic medications to the eye. Researches conducted with vitreous ground drugs and nanomaterials for drug delivery will undoubtedly keep enhancing the effectiveness of ocular drug delivery systems with the aid of nanotechnology in order to reach the desired system for ideal periocular medication delivery.

4.2. Oncology drug delivery

Cancer treatment has recently benefited from nanotechnology with the approval of a number of early nanodrug delivery systems. Historically, drug delivery techniques have emphasized passive targeting by increasing the blood flow permeability of malignant cells. In recent years, active targeting using cell-specific ligands has gained popularity [10]. This adaptable approach has increased the possibility for drug delivery systems with several concurrent functions, including applications in therapy, imaging, and diagnostics that will enhance treatment choices for patients with cancer that is still in its early stages. The capacity to maintain drugs that are disseminated in the circulation and improve their water solubility are only two of the advantages of using nanomaterials in pharmaceutical formulations. Additionally, the pharmacological and pharmacokinetic properties of medications may be improved by using nanocarriers. The toxicity of metal-based nanoparticles and the topic of nanotoxicology remain major concerns despite the advantages, which are substantial. Overall, the development of nanomaterial drug carriers, such as liposomes, polymeric nanoparticles, dendrimers, and nanomicelles, for the detection and treatment of different malignancies offers great potential for clinical applications.

4.3. Vaccines

The use of nanotechnology in drug development has many advantages. It is possible to use nanoparticles as transporters for substances such as proteins and desired drugs [11], as shown in Figure 3. Low toxicity and non-degradability of polymeric nanoparticles (through mucosal membranes) can promote the formation of immune responses by antigens. Additionally, nanoparticles can be used in vaccine delivery systems because they can better maintain the strength of the antigen's activity. Polymeric materials can be used as carriers and vaccine adjuvants when paired with extended release, targeted drug delivery, and various delivery mechanisms and routes in the field of creating vaccines and pharmaceuticals. Overall, there is a lot of potential for using nanomaterials to develop new immunization and medicine delivery methods.

Polymer-based nanomaterials can be used as delivery vehicles for vaccines, and mucosal route vaccines have great potential as mucosal and systemic immunity can be stimulated through mucosal application. Mucosal vaccines have a number of benefits including stopping the entry of pathogens into the body, stopping pathogen inactivation, stopping the spread of pathogens and are simpler to use, have a lower risk of spreading infection and may be easier to produce. Through continuous release, nano-vaccines can improve humoral, cell-mediated, and mucosal immune responses and shield loaded antigens from deterioration. The advantages of organic material carriers are their relative safety, lack of toxicity, lack of immunogenicity, and lack of carcinogenicity, which makes them more promising for use. The key benefits of polymer-based organic nanomaterials as carriers include: non-viral carriers, non-immunogenicity, strong biocompatibility, and a significant amount of specific surface area. They are simple to load with model medications and deliver to certain cells, tissues, or organs. The use of vaccinations for humans and animals will profit significantly from these specific benefits. Considerably enhance the usage of vaccinations for both humans and animals.

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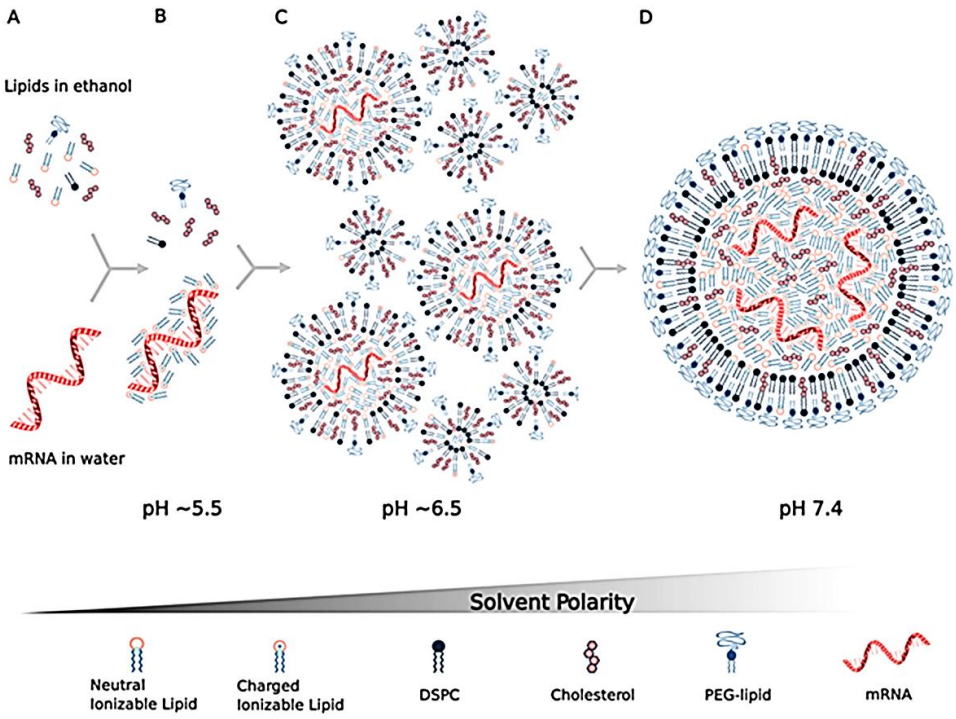


Figure 3. The common methods for mRNA lipid nanoparticle production [11].

4.4. Diagnostic test

Fluorescent nanoparticles provide researchers with a means to get over the problems created by the inadequacy of procedures employed for diagnostic testing by fluorescent markers, such as fluorescence fading after a single usage, color matching, and restricting the use of dyes owing to bleeding effects [12].

One of the most important findings is the ability to customize quantum dots in many clear colors. The following advantages of labelled quantum dots include the fact that they are excitable when using white light and that they can be associated with biomolecules that can spend a great deal of time exploring various biological mechanisms in living systems [13]. This technology also allows one to monitor many biological events simultaneously by labelling various biomolecules with specific colored nanodots. More importantly, the therapeutic and diagnostic nanoparticles are achieved by combining the drug in and the visualizer in a different intelligent formulation, where the path and positioning of these nanoparticles at the target site and the drug action can be detected to assess the therapeutic response. Thus, nanomaterials are again to have a good potential use in diagnostic testing.

5. Conclusion

Specifically, this research concentrates on drug delivery and analyzes the different types of drug delivery systems applicable to drug delivery systems as well as the real-world applications of nanomaterials for drug delivery. This research's motivation is to look at the diverse range of functional nanomaterials applications in drug delivery. The relevance of the study, recent discoveries, and uses of nanomaterials for medication administration have all been discussed in the publication. Drug delivery systems have certain constraints, such as a usually poor drug loading capacity and the difficulty to load big molecule medications onto nanocarriers. Current research has been hampered in a number of ways by theoretical and methodological restrictions, including the development of more effective formulations for long-lasting formulations, overcoming biological barriers, and increasing the water solubility of insoluble pharmaceuticals. However, there are several advantages to using drug delivery

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systems, such as better medication effectiveness, lower costs, and fewer side effects. Overall, the delivery of drugs via nanomaterials is still an important and promising field of study.

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