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Applications of Nano Formulation: New Innovation in Improving Drug Delivery

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ABSTRACT

ANanoparticles are a revolutionary medication delivery technology, as we all know. They have several positive impacts, such as the drug's efficacy and safety. We enumerate their efficaciousness during drug distribution in this review. One of the methods for more precisely delivering pharmacological substances to the intended tissue while lowering the total dosage and possible harmful side effects is drug nanoformulation. They may function as carriers of various active medicinal ingredients into a particularly body regions, or they may be therapeutic agents in and of themselves. As a truly multidisciplinary field of study, nanotechnology has benefited greatly from the contributions of chemists, physicists, biologists, and pharmaceutical scientists in the development of novel therapeutic and diagnostic approaches. The application of nanotechnology has advanced non-invasive imaging, nutraceutical delivery, cancer and HIV/AIDS treatment, and more. There are many benefits to using micro and nanoparticles in biomedicine, particularly when it comes to drug delivery, over traditional methods which include improved drug delivery, high-performance properties of the product, using less costly drug concentrations in the delivery systems, extending the drug's bioactivity by shielding it from environmental effects in biological media, and more effective treatment with fewer side effects.

KEY WORDS: NANOPARTICLES, LIPOSOMES, SURFACE AREA, SHAPE, NANO FORMULATION, NANOFORMULATIONS IMPROVING DRUG DELIVERY.

INTRODUCTION

Polymeric particles made of synthetic or natural polymers, known as nanoparticles, are spherical in shape. Their sizes vary from 10 to 500 nm. These particles offer a wide range of possible uses due to their spherical form and high surface area to volume ratio. Nanoparticle size and surface characteristics have been studied to improve bioavailability, reduce clearance, and boost stability. By regulating these properties, the medication can now reach bodily tissue that might not have previously been reachable. Nanoparticles are divided into several categories based on their size, shape, and material qualities (Haleem et al., 2023).

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Furthermore, nanoparticles can be hard (such as titania [titanium dioxide], silica [silica dioxide] particles, and fullerenes) or soft (such as liposomes, vesicles, and nanodroplets). The classification of nanoparticles often relies on their use, such as in diagnosis or therapy vs fundamental research, or it may be connected to how they were generated. They have also aided in the development of new techniques of administering treatment, such as giving local warmth (hyperthermia), limiting vasculature to sick tissues and tumors, and transporting medication payloads (Al-Abduljabbar & Farooq 2023).

Magnetic nanoparticles have been used to trace the progression of cancer along lymph nodes in place of radioactive technetium. The nanoparticles function by taking advantage of the contrast change caused by microscopic particles of superparamagnetic iron oxide in magnetic resonance imaging (MRI). Such particles can also be utilized

to eliminate tumors by hyperthermia, which involves heating and destroying tissue on a small scale using an alternating magnetic field (Crintea et al., 2022).

Nanoparticles can be created to improve fluorescence imaging, positron emission tomography (PET), or ultrasound pictures. These strategies often need the nanoparticle's ability to recognize a certain cell or disease condition. The medication might be delivered by a nano capsule or a liposome, or it could be delivered in a porous nano sponge structure and then kept in place by bonding at the targeted spot, allowing for delayed drug release. The creation of nanoparticles to help with medicine delivery to the brain by inhalation offers great potential for the treatment of neurological illnesses such as Parkinson's, Alzheimer's, and multiple sclerosis (Jain et al, 2018). Nano formulation of drugs is one strategy to deliver pharmaceutical agents more precisely to the targeted tissue and reduce the overall dose and potentially toxic side effects (Choi et al., 2023).

Types of nano formulations: Nanocrystal: Nanocrystals have been utilized to deliver insoluble medicines like paclitaxel. PEGylation is a critical idea that extends the circulation duration of the nanocarrier system and enhances medication therapeutic outcomes (Sun et al., 2008).

Nanocapsule: This has the potential to increase medication stability and bioavailability. Peptides, hormones, proteins, enzymes, medicines, metabolites, or reporter molecules may be protected from biological and chemical degradation using nano capsules (Janeth et al., 2017).

Nanospheres: Nanospheres are used in anti-wrinkle creams, moisturizing creams, and anti-acne nanoparticle creams. Nanospheres are utilized to transport active ingredients deeper into the skin, as well as to preserve the active component from enzymatic or chemical destruction or to provide a regulated release. In the case of scents, this delivery mechanism was found to extend active release (Prieto et al., 2017).

Nanosponges: They can solubilize weakly water-soluble medicines, resulting in extended release and improved medication bioavailability. The two primary therapeutic applications for nanosponges are targeted drug delivery (ensuring that the medicine reaches the target cells in the body, such as cancer cells) and enhanced drug delivery, which allows for improved physical qualities of pharmaceuticals (e.g., solubility).

Nanoprecipitation: This technique involves quickly injecting a drug solution into an aqueous phase after it has been dissolved in a water-miscible organic solvent. Drugs precipitate quickly in aqueous media, forming nanoscale drug particles.

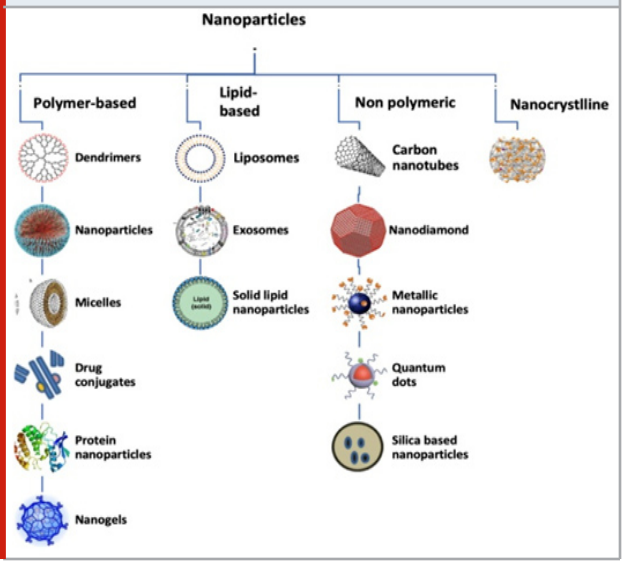
Nano Formulation Based on Emulsions: Preparing an oil-in-water or water-in-oil emulsion and then letting the solvent evaporate to produce nanoparticles is known as solvent evaporation. [16] It includes phase inversion and spray drying (Sun et al., 2022).

Coacervation: In this method, a polymer solution is phase separated into a coacervate phase, which contains the medication. Upon solidification of the coacervate phase, nanoparticles may develop.

Electronspinning: Electrospinning is mainly used to manufacture nanofibers, but with the right formulations, it can also be utilized to produce nanosized particles.

Technology of Supercritical Fluids: Supercritical Antisolvent Process: To precipitate nanoparticles from a solution, antisolvents such as carbon dioxide are employed at supercritical temperatures. [20] Supercritical Fluid Extraction of Emulsions: In order, to extract nanoparticles from an emulsion, supercritical fluids must first be generated.

Figure 1: Types of Nanoparticles.



Nano carriers used in nanoformulation: Materials known as nano carriers are made with the purpose of encapsulating and delivering medicinal medicines, imaging agents, or other payloads in a precise and regulated way. These carriers play a crucial role in nanoformulations, improving medication stability, bioavailability, and solubility while frequently enabling tailored administration (Marianna Foldvari 2010). The following are a few typical nano

Carriers found in nanoformulations:

Liposomes: Lipid bilayers form the spherical vesicles known as liposomes. In their lipid bilayers or aqueous core, they can contain hydrophilic or hydrophobic medications, respectively. Liposomes can be used for a variety of medication delivery applications because they are biocompatible and adaptable (Zhang et al., 2018).

Polymeric nanoparticles: Biocompatible and biodegradable polymers are used to create polymeric nanoparticles. They can be made to release medications gradually or under strict supervision. Chitosan nanoparticles and poly (lactic-co-glycolic acid) (PLGA) nanoparticles are two examples.

Micelles: Made up of amphiphilic molecules, micelles are self-assembling structures. When these molecules are present in concentrations higher than their critical micelle concentration (CMC), they form. Drug distribution can be improved when hydrophobic medications are dissolved in the center of micelles.

Nanocapsules: Having a core-shell structure, nanocapsules are nanoscale capsules. Drugs can be accommodated in the core, while proteins, polymers, or lipids are frequently found in the shell. It is possible to encapsulate both hydrophobic and hydrophilic molecules using this architecture.

Dendrimers: Having a distinct structure, dendrimers are highly branching macromolecules. Their size and surface functionality can be precisely controlled during their synthetic process. Drugs or imaging agents are frequently encapsulated inside of dendrimers.

Solid Lipid Nanoparticles: Solid Lipid Nanoparticles (SLNs) are room-temperature, lipid-based nanoparticles in a solid state. In comparison to conventional liposomes, they provide better stability and regulated release. Drugs can be shielded from deterioration by the lipid matrix.

Carbon nanotubes: Therapeutic compounds can be carried via carbon nanotubes, which are cylindrical structures with special features. Functionalized carbon nanotubes can be used as delivery systems for different payloads, such as imaging agents or drugs (Ganesh et al., 2015).

Metal nanoparticles: As carriers, metal nanoparticles derived from gold, silver, or iron oxide can be employed. Their surfaces can be functionalized for drug loading or targeting, and they may possess special features.

Cyclodextrins: Cyclodextrins are cyclic oligosaccharides that have ability to combine with hydrophobic medications to form inclusion complexes that increase the solubility of the former. They can serve as drug delivery vehicles, particularly for medications that are not very soluble in water (Patel et al., 2020).

Protein-based Nanoparticles: Drug delivery nanoparticles can be formed from proteins, such as albumin or gelatin. These protein-based carriers can be engineered to have particularly targeting characteristics and are biocompatible.

Applications of nano formulation: Applications for nanoformulations can be found in many different domains, and they provide benefits like focused therapy, increased therapeutic efficacy, and better drug distribution. It includes1) Drug Delivery 2) Targeted Drug Delivery 3) Sustained Release 4) Cancer Therapy 5) Imaging and Diagnostics 6) Vaccines 7) Gene Delivery 8) Cosmetics & Personal Care 9) Agriculture 10) Food and Nutraceuticals 11) Wound Healing 12) Environmental Remediation To guarantee safety, scalability, and regulatory compliance in these applications, however, further research is necessary.

Methods used to improve drug delivery in nano formulation: One of the most important facets of pharmaceutical research and development is enhancing medication delivery. A range of techniques and tools are used to improve medication delivery's effectiveness, safety, and specificity. Here are some essential techniques for

Enhancing medication delivery:

Nanotechnology: Using nanoscale carriers to encapsulate medications, such as liposomes, micelles, polymeric nanoparticles, and dendrimers. This improves stability and solubility and enables tailored distribution.

Systems of Lipid-Based Delivery: Lipid vesicles known as liposomes are capable of encasing medications that are hydrophilic or hydrophobic. They enhance the stability and solubility of drugs and can help with targeted distribution. Lipid-based nanoparticles with regulated drug release and improved bioavailability are called solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs).

Delivery Systems for Polymers:

Polymeric Nanoparticles: Nanoparticles for controlled medication release can be made from biodegradable and biocompatible polymers and targeted delivery.

Polymeric Micelles: Amphiphilic block copolymers self-assemble to generate self-assembling structures that improve the solubility of hydrophobic medicines.

Drug Pairs: Prodrug Design: The process of chemically modifying pharmaceuticals to produce prodrugs that, in their original form, are inactive or less active. In vivo activation enhances medication delivery and stability. Drugs and antibodies are linked to create antibody-drug conjugates (ADCs), which are then specifically delivered to target cells, such cancer cells. Encasing medication particles in microspheres or microcapsules to prevent deterioration and enable regulated release is known as microencapsulation.

Targeted Administration of Medicines: Active targeting is the process of delivering drugs to the intended location on cells by utilizing ligands, such as peptides or antibodies, to target particular receptors. Using the enhanced permeability and retention (EPR) effect in tumors, where leaky blood arteries allow nanoparticles to enter the body, is known as passive targeting. Using the increased permeability and retention (EPR) effect in tumors—where leaky blood arteries enable nanoparticles to aggregate preferentially in malignant tissues—is known as passive targeting.

Microneedle Technology: Transdermal drug delivery by microneedles allows for regulated release of medication by avoiding the epidermal barrier.

Electrospinning: This technique produces nanofibers that are used in tissue engineering, medication delivery, and wound healing.

Ultrasound-mediated delivery: The process of using ultrasound to improve drug penetration into tissues or cells, is referred to as ultrasound-mediated delivery.

Microfluidics: Using microfluidic devices to carefully manage the formulation process to produce nanoparticles or microcapsules with desired qualities is known as microfluidics.

Magnetic Drug Delivery: To improve targeted drug delivery, magnetic nanoparticles are guided to precise places using magnetic fields. Creating responsive systems that release medications in response to particularly stimulus, such as pH, temperature, or enzyme activity, is known as "smart drug delivery."

Routes of administration for nanoformulation: The drug's properties, the intended site of action, and the intended therapeutic outcome all influence the delivery method selection. The following are some typical medication delivery pathways for nanoformulations: Oral Administration, Intravenous Administration, Transdermal Delivery Intramuscular and Subcutaneous Injection Inhalation, Intrathecal and Intraventricular Administration, Intraperitoneal Administration, Ocular Delivery, Nasal Delivery, Delivery via Vagina and Rectal, Intradermal Delivery& Intraperitoneal Delivery. The advantages and disadvantages of each administration route are taken into consideration, while designing nanoformulations in order, to maximize drug delivery for certain therapeutic uses.

Factors that improve drug delivery in nano formulation: By using nanoscale carriers to address issues with drug solubility, stability, and targeted distribution, nanoformulations aim to improve drug delivery. The following elements influence how well drugs are delivered in nanoformulations:

Greater Surface Area: When compared to traditional formulations, nanoformulations offer a noticeably larger surface area. Better interactions with biological systems are made possible by the increased surface area, which enhances medication distribution and absorption.

Better Solubility: Hydrophobic medications' poor solubility is addressed via nanoformulations. Drug solubility and bioavailability are improved when drug particles are reduced to the nanoscale because this improves the effective surface area exposed to the surrounding medium.

Improved Bioavailability: Rapid drug absorption and distribution are made possible by the tiny particle size and larger surface area of nanoparticles, which enhances bioavailability. This is crucial for medications whose oral bioavailability is limited.

Long-term Sustained and Controlled Drug Release: Drugs can be released over an extended period of time with the use of nano formulations. This controlled release profile enhances patient compliance, lowers adverse effects, and maintains therapeutic medication levels.

Targeted Drug Delivery: Certain tissues or cells can get drugs in a targeted manner thanks to nano formulations. While passive targeting can be accomplished by the increased permeability and retention (EPR) effect in some pathological circumstances, such as tumor tissues, active targeting is facilitated by surface modifications using ligands or antibodies.

Protection of Drugs: Liposomes and nanoparticles are examples of nanocarriers that can shield pharmaceuticals from enzymatic or adverse environmental degradation. During transportation and storage, this protection improves the stability of medications.

Better Cellular Uptake: Drugs that have trouble crossing cell membranes can benefit from nano formulations, which can improve cellular uptake. It is possible to use a variety of methods, such as receptor-mediated endocytosis, to help drugs enter target cells.

Decreased Side Effects: In nano formulations, targeted medication administration and controlled release help to minimize off-target effects and lower systemic toxicity. This is especially helpful for cancer treatment and other illnesses where accurate medication localization is essential.

Biocompatibility: To guarantee that nano formulations are compatible with biological systems, biocompatible materials are frequently used in their creation. This lowers the possibility of negative reactions and raises the medication delivery system's safety rating.

Customized Surface Properties: By altering their surface, nanoparticles can be made to exhibit particularly characteristics like greater target cell contact, enhanced stability, or stealth behavior—a lower capacity to be recognized by the immune system.

Multifunctional Platforms: By combining therapeutic pharmaceuticals with imaging or diagnostic agents, nano formulations can function as multifunctional platforms. This allows for simultaneous diagnosis and therapy.

Administration Ease: Based on the demands of the patient and the properties of the medicine, nano formulations can be created for a variety of administration routes, such as oral, intravenous, transdermal, or inhalation. This flexibility in drug delivery allows for customized treatment plans. These variables must be carefully taken into consideration, keeping in mind the unique characteristics of the medication and the intended therapeutic objectives, so nano formulations to be applied successfully.

Nano formulation improving drug delivery: The following are some ways that drug distribution can be enhanced by nanoformulations:

Enhancement of Bioavailability: Poorly water-soluble medications can become more soluble thanks to nanoformulations, which increases their absorption and bioavailability. Better absorption of medications is made

possible by the protective action of nanoparticles against gastrointestinal tract degradation.

Targeted Administration of Medicines: Targeting particularly tissues, cells, or organs with functionalized nanoparticles can minimize off-target effects and enhance therapeutic results. Adding ligands to targets is known as active targeting. Attaching ligands to the nanoparticles that enable them to identify and bind to certain receptors on target cells is known as active targeting.

Prolonged Release: Drugs can be released from nanoformulations in a regulated or sustained manner, resulting in a longer duration of action and fewer dosage adjustments.

Defence of Pharmaceutical Molecules: Drugs can be more stable in biological settings by using nanoparticles to shield them from enzymatic or chemical processes that could break them down.

Delivery Within Cells: Drugs can be delivered intracellularly more easily with the help of nanoparticles, reaching their intended locations inside cells.

Diminished Adverse Reactions: By limiting the amount of time, medication is exposed to healthy tissues, targeted delivery can lower the likelihood of adverse consequences.

Combination Counselling: Co-delivery of several medications is made possible by nanoformulations, which enables combination therapy with beneficial effects.

Diagnostic Imaging: Nanoparticles can be employed as diagnostic instruments for illnesses or as imaging agents to see how drugs are distributed throughout the body.

Personalized Health Care: Personalized medicine can be advanced by customizing nanoformulations to each patient's unique set of traits.

Non-intrusive Administration Routes: As an alternative to more conventional delivery methods like oral or intravenous injection, nanoparticles can be engineered for non-invasive routes like transdermal or nasal distribution.

Cells/Tissues helping in drug delivery: Different cells and tissues can be used or targeted in medication delivery to improve the safety, effectiveness, and selectivity of medicinal medicines. The following tissues and cells are

Frequently used in medication delivery: The inner surface of blood arteries is lined with endothelial cells. It is possible to create nanoparticles to get through the endothelium barrier and deliver them specifically to particularly tissues or organs.

Macrophages: As a component of the immune system, macrophages can be used to carry drugs, particularly to inflammatory regions. It is possible to engineer nanoparticles such that they are specifically delivered to areas of infection or inflammation and are absorbed by macrophages.

Hepatocytes, or liver cells: Because the liver is involved in drug processing, it is frequently the target of drug delivery methods. It is possible to engineer nanoparticles so that they gather in hepatocytes, which would improve the administration of medications that the liver must metabolize or be used to treat liver illnesses.

Cancer Cells: One of the main goals of medication distribution is to target cancer cells. In order to minimize side effects, nanoparticles can be functionalized to recognize and deliver medications to cancer cells only, sparing healthy cells.

Immune cells: Vaccines and immunotherapies can be developed specifically targeting immune cells, such as dendritic cells. Antigens or therapeutic substances that elicit an immune response can be delivered using nanoparticles.

Central Nervous System (CNS) Cells: The blood-brain barrier makes it difficult to transfer drugs to the brain. It is possible to create nanoparticles that can get through this barrier, making the treatment of neurological conditions easier.

Skin Cells: Transdermal drug administration delivers medications locally or systemically by targeting the skin. Drugs can be progressively released from nanoparticles by making them able to permeate the layers of skin.

Bone Cells: Osteoporosis and bone cancer can be treated by targeted medicine delivery using nanoparticles to the bone tissue.

Mucosal Cells: Local medication administration or systemic absorption can be directed towards mucosal surfaces, such as those found in the respiratory and gastrointestinal systems. Through mucosal barriers, medication absorption can be improved by nanoparticles.

Tumor Vasculature: Drug delivery strategies can target the distinct features of blood arteries found within tumors. It is possible to engineer nanoparticles so that they selectively collect in tumor blood arteries, enhancing medication delivery to the tumor.

Red Blood Cells: To improve distribution to particularly organs and extend circulation periods, drug-loaded nanoparticles can be encapsulated or adhered to red blood cells.

Lymphatic System: Drug delivery to lymph nodes and tissues connected to the immune response is made possible by the ability of nanoparticles to specifically target the lymphatic system.

Synovial Cells: To administer anti-inflammatory medications to synovial cells in the joints, such as in rheumatoid arthritis, nanoparticles can be specifically targeted to these cells. Through the utilization of distinct cell and tissue properties, scientists can create drug delivery systems that optimize therapeutic effects while reducing

side effects. In order, enhance patient care, the discipline of nanomedicine is still investigating novel strategies for targeted drug delivery.

CONCLUSION

This review makes it clear that the use of nontechnology in medicine and drug delivery has created new avenues for individualized and secure treatment options. In the end, researchers are able to administer medications for longer periods of time with less frequent doses (sustained release), higher precision, and penetration in difficult-to-access tissues through the alteration of molecular size and surface features. There are many benefits to using micro and nanoparticles in biomedicine, particularly when it comes to drug delivery, over traditional methods which include improved drug delivery, high-performance properties of the product, using less costly drug concentrations in the delivery systems, extending the drug's bioactivity by shielding it from environmental effects in biological media, and more effective treatment with fewer side effects.

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