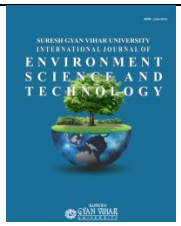

SGVU International Journal of Environment, Science and Technology

Journal homepage: https://www.gyanvihar.org/researchjournals/envirmental_science.php

E-ISSN:

Vol. 10 Issue 01Page No 17- 30

Review article

Nanotechnology in Pharmacy: AnExtensive Review

Nikhil S. Shrisunder*, Dr. Gaurav Gupta

School of Pharmacy, Suresh Gyan Vihar University, Jaipur, India

*Corresponding author's e-mail addresses: nikhilshrisunder1989@gmail.com

Received:

Keywords

Nanotechnology
Migraine
drug delivery systems
drug development
Targeted therapy
Controlled release
Site-specific delivery
Therapeutic efficacy

Abstract

The rapid advancements in nanotechnology have revolutionized various fields, including medicine, by offering innovative instruments and methods for diagnostics, treatment, and targeted novel drug delivery. This comprehensive review provides a thorough analysis of the current state of nanotechnology applications in medicine, highlighting its potential to transform healthcare. The review begins by introducing the fundamental concepts of nanotechnology and its relevance to medical applications. It elaborates on the unique properties of nanoparticles, such as their size-dependent behaviours and high surface area-to-volume ratios, which enable precise manipulation at the nanoscale. Subsequently, the review delves into the diverse roles of nanotechnology in medicine, spanning diagnostic imaging techniques, therapeutic interventions, and personalized medicine. The section on drug formulation explores how nanotechnology has paved the way forinnovative drug delivery methods, including nanoemulsions, nanosuspensions, and solid lipid nanoparticles. It discusses how these systems can improve drug solubility, bioavailability, and controlled release profiles, thereby addressing longstanding challenges in pharmaceutical development. This approach minimizes systemic toxicity and maximizes therapeutic efficacy, a vital advancement in the realm of patient-centred care. This review underscores that nanotechnology on the field of pharmacy, offering unparalleled opportunities for advancing drug development

	and patient care. By synthesizing current research insights, challenges, and future directions, this review serves as an indispensable guide for researchers, pharmaceutical professionals and policymakers aiming to harness the full potential of nanotechnology in reshaping the landscape of pharmacy.

Introduction

Nanotechnology, a cutting-edge interdisciplinary field, has rapidly emerged as a revolutionary force in various industries, none more so than in pharmacy. The convergence of nanotechnology and pharmacy has led to ground-breaking advancements that are reshaping drug development, delivery systems, and therapeutic strategies. This extensive review aims to provide a comprehensive overview of the multifaceted applications of nanotechnology in the realm of pharmacy, highlighting its profound impact on optimizing drug efficacy, safety, and patient-centric care. Nanotechnology operates at the nanoscale, where materials and systems exhibit unique properties due to their size and structure. This review begins by establishing the fundamental principles of nanotechnology and its relevance to the pharmaceutical landscape. At the nanoscale, particles behave differently than their bulk counterparts, and these distinct behaviours open up new avenues for innovation in drug formulation, delivery, and personalized medicine. The integration of nanotechnology with pharmacy has resulted in innovative drug delivery systems that have overcome traditional limitations. By formulating drugs as nanoparticles, nanoemulsions, nanosuspensions, or nanoparticles of solid-lipid complex, the solubility, stability, and release profiles of drugs could be finely tuned, enabling more effective treatments. These advancements have transformed the landscape of drug formulation, enhancing the bioavailability of poorly soluble drugs and facilitating controlled release for sustained therapeutic effects(Sim et.al., 2021). One of the most significant achievements of nanotechnology in pharmacy is the development of targeted drug delivery systems. Nanoparticles, skilfully engineered and surface-functionalized, can navigate physiological barriers, selectively accumulate at disease sites, and release therapeutic payloads in a controlled manner. This innovation minimizes off-target effects, reduces systemic toxicity, and amplifies the therapeutic impact of pharmaceutical agents. Thus, nanotechnology has started a new era of precision pharmacotherapy (Drexler et.al., 1986).

Need for dosage forms based on Nanotechnology

Nanotechnology-based dosage forms have become imperative in modern pharmaceutical research and development due to their potential to address a myriad of challenges associated with traditional drug formulations. These challenges encompass issues related to drug solubility, bioavailability, targeting specificity, sustained release, and personalized medicine.(Mashaghi et.al., 2013). The incorporation of nanotechnology into dosage forms offers several compelling reasons for its adoption:

i. Enhanced Bioavailability: Many drug compounds suffer from poor solubility and low bioavailability, leading to suboptimal therapeutic outcomes. Nanotechnology allows for the formulation of drugs as nanoparticles, which increases their surface area and dissolution rate, thereby improving bioavailability and ensuring effective drug delivery (Medina et.al., 2007).

ii. Targeted drug delivery: Drug distribution to particular sites can be facilitated by engineering nanoparticles to specifically target cells, tissues, or organs. By navigating biological barriers like the blood-brain barrier and accumulating at illness locations, functionalized nanoparticles can reduce adverse effects and improve the effectiveness of therapy (Morganet.al., 2005).

iii. Sustained and Controlled release: Nanotechnology enables the design of drug delivery systems with controlled release profiles. This is necessary for drugs with a narrow therapeutic window or for those requiring long-term administration, ensuring consistent drug levels and minimizing fluctuations that can lead to side effects or reduced efficacy.

iv. Minimized side effects: Nanotechnology-based dosage forms can decrease off-target effects and lower the required dosage by delivering medications directly to the target site. This raises patient satisfaction levels overall and increases treatment compliance in addition to improving patient safety (Kakade et.al., 2013).

v. Combination therapies: Nanoparticles can carry multiple therapeutic agents, enabling combination therapies to treat complex diseases more effectively. This approach is valuable especially in cancer treatment, where multiple drugs with different mechanisms of action can be combined in a single nanoparticle formulation (Wickline et.al., 2003).

vi. Personalized Medicine: Nanotechnology facilitates the development of personalized medicine by allowing tailored drug formulations based on individual patient characteristics.
This includes factors such as genetic makeup, disease profile, and treatment response, leading to optimized therapeutic outcomes.

vii. Overcoming biological barriers: Nanoscale drug carriers can overcome physiological barriers, such as mucosal surfaces, cell membranes, and the blood-brain barrier, enabling the administration of drugs to previously inaccessible sites and expanding the range of treatable conditions.

viii. Reduced frequency of administration: Improved drug stability and controlled release achieved through nanotechnology can extend the duration of drug action. This reduces the frequency of administration, enhancing patient convenience and adherence to treatment regimens (Vemuri et.al.,1995).

ix. Regenerative medicine and Gene therapy: Nanotechnology enables the administration of nucleic acids, proteins, and growth factors, making it a promising platform for regenerative medicine and gene therapy. This opens avenues for treating genetic disorders and promoting tissue regeneration.

Nanotechnology based dosage forms

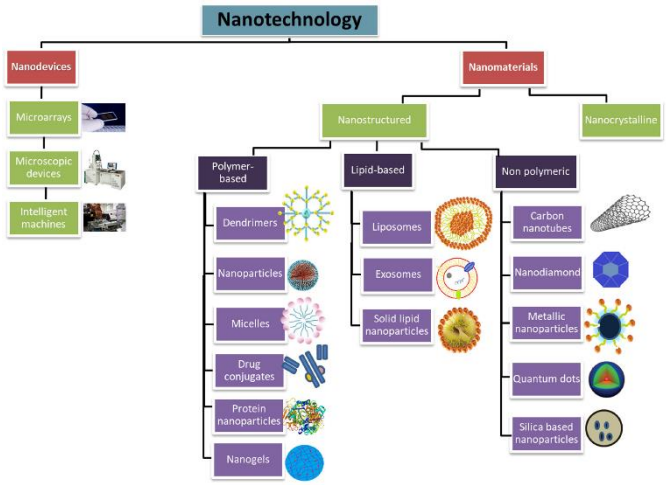

Fig No.1- Classification of Nanotechnology based formulations(Yetisgin et.al., 2020)

Liposomes

These are lipid bilayer-based spherical vesicles that have the ability to enclose both hydrophobic along with hydrophilic substances. They provide a means to encapsulate and provide therapeutic chemicals in a regulated and focused way, which makes them popular choices for drug delivery systems (Anton et.al., 2008). There are several ways to prepare liposomes, and each has benefits and drawbacks of its own. Here are a few common methods for liposome preparation:

a. Thin Film Hydration Method:

This is one of the most widely used methods for liposome preparation.

Lipids (phospholipids and cholesterol) are dissolved in an organic solvent to create a thin lipid film on the walls of a round-bottomed flask.

The organic solvent is then evaporated under reduced pressure to form a lipid film.

An aqueous solution containing the desired drug or molecule is added to the lipid film, and the mixture is subjected to agitation or vortexing to hydrate the lipids and form liposomes.

The resulting liposome dispersion is then typically extruded through polycarbonate membranes to achieve a more uniform size distribution.

b. Reverse Phase Evaporation Method:

This method is suitable for encapsulating hydrophilic compounds.

An organic solvent dissolves lipids and aqueous solutions containing the medication. After that, the organic solvent evaporates, leaving behind a water-in-oil (W/O) emulsion. After that, this emulsion is stirred while being combined with a surplus of an aqueous phase. Liposomes arise as a result of the evaporation of the organic solvent (Tibbals et.al.,2011).

c. Extrusion method:

This method is often used in combination with other preparation methods to achieve a more uniform size distribution of liposomes. The liposome suspension is forced through a series of polycarbonate membranes with defined pore sizes using an extrusion apparatus.

This process helps in reducing the size of liposomes and obtaining a more homogenous population.

Several liposome-based formulations have been developed and marketed for various applications in the fields of pharmaceuticals, cosmetics, and diagnostics (Rizzo et.al., 2013). Some of these marketed liposome preparations include:

Doxil (Doxirubicin Liposomal): It is a liposomal formulation of the chemotherapy drug doxorubicin. It is used for the treatment of various cancers, including ovarian cancer, multiple myeloma, and Kaposi's sarcoma. Doxil's liposomal encapsulation allows for prolonged circulation and preferential accumulation in tumor tissues, reducing side effects.

AmBisome (Amphoterecin B Liposomal): It is a liposomal version of amphotericin B, an antifungal medication. Severe fungal infections, such as those brought on by Aspergillus and Candida species, are treated with it. Liposomal encapsulation lessens the nephrotoxicity linked to traditional amphotericin B and enhances the safety profile of the medication.

Nanoparticles:

The synthetic variety or semisynthetic polymers are the building blocks of nano- or subnano-sized objects known as nanoparticles. Herbal medicine nanoparticles have garnered a lot of

interest lately. Colloidal systems with particles ranging in size from 10 nm to 1000 nm are known as nanoparticles. Because the formulation may be easily encapsulated in and transported to the effective site, it is an effective system. The solid-core, spherical particles with nanometric size known as nanospheres. The drug is either absorbed onto the surface or implanted in the matrix of the nanocapsules. The drug is encapsulated within the primary portion of the vesicular system, which is surrounded by an embryonic continuous polymeric sheath (Debbage et.al., 2008).

Here are some common methods for preparing nanoparticles:

a. Sol-gel technique:

This technique is used to synthesize nanoparticles from precursor solutions.

In a sol-gel process, a precursor solution containing metal salts or metal-organic compounds is hydrolysed and polymerized to form a gel.

The gel is then subjected to drying and calcination processes to form nanoparticles.

b. Chemical Precipitation method:

Using a suitable reducing or precipitating agent, soluble metal salts are precipitated from solution to create nanoparticles in this process.

The reaction between the metal ions and the reducing or precipitating agent results in the formation of nanoparticles.

c. Co-precipitation method:

This method involves the simultaneous precipitation of two or more compounds to form nanoparticles.

By controlling the reaction conditions and precursor concentrations, nanoparticles with desired properties can be obtained.

d. Physical Vapour Deposition:

PVD methods involve the vaporization of a solid material followed by its condensation onto a substrate, resulting in nanoparticle formation.

Techniques like sputtering and evaporation are used to create nanoparticles with precise control over composition and size.

e. Chemical Vapour Deposition:

CVD methods involve the reaction of gaseous precursors to form nanoparticles on a substrate surface. This method is commonly used to produce nanoparticles of materials like carbon nanotubes and semiconductor compounds.

Numerous nanoparticles-based formulations have been developed and marketed for various applications across industries, including medicine, electronics, cosmetics, and more. These formulations leverage the unique properties of nanoparticles to enhance product performance and achieve specific functionalities (Chang et.al., 2011). Here are a few examples of nanoparticles-based marketed preparations:

Abraxan (Albumin bound paclitaxel nanparticles): It is a nanoparticle formulation of the chemotherapy drug paclitaxel. Paclitaxel nanoparticles are encapsulated within albumin protein, improving solubility and reducing side effects. Abraxane is targeted to treat breast cancer, lung cancer, and pancreatic cancer.

Combidex (Ferummoxtran-10 nanoparticles): This is a nanoparticle contrast agent used for magnetic resonance imaging (MRI) to detect lymph node metastases. Ferumoxtran-10 nanoparticles are injected into the bloodstream and accumulate in lymph nodes, making them visible in MRI scans.

Microspheres:

Small spherical particles, typically ranging in diameter from 1 μm to 1000 μm (1 mm), make up microspheres. Microspheres are also known as microparticles. One can make microspheres from a broad variety of natural and manmade materials (Caster et.al., 2016). Microspheres made of glass, polymers, and ceramic materials are offered for sale. Microspheres fall into two categories: biodegradable and non-biodegradable. Biodegradable microspheres include protein microspheres, modified starch microspheres, gelatine microspheres, polypropylene dextran microspheres, polylactic acid microspheres, as well as so on. According to the body of research that has been done on non-biodegradable microspheres, polylactic acid is the only polymer that is approved for use by humans and is used as a controlled-release agent. Numerous methods are employed in the preparation of microspheres to control their shape, size, and properties.(Muller et.al., 2000).Here are some common methods for preparing microspheres:

a. Emulsion-solvent evaporation technique:

Using this technique, a polymer (such polylactic-co-glycolic acid, or PLGA) is dissolved in a volatile chemical solvent to produce a polymer solution.

Oil-in-water (O/W) emulsion is created by emulsifying the polymer solution in an insoluble continuous phase (often an aqueous solution) with the aid of surfactants. Following the evaporation of the organic solvent, the polymer droplets solidify and microspheres form.

b. Spray drying:

It involves atomizing a polymer solution or suspension into fine droplets in a heated chamber. The solvent evaporates rapidly, leaving behind solid microspheres (Trotta et.al., 2003).

This method is suitable for heat-stable polymers and usually used for preparing microspheres with controlled drug release profiles.

c. Coacervation:

A polymer is separated from the solution into a phase that is rich in polymers using this phase separation process.

In order to create some thick phase rich in polymers, complex coacervation entails an association of oppositely charged polymers.

Microspheres are formed when the dense phase is solidified.

d. Hot melt microencapsulation:

This method involves melting a polymer with a drug or active ingredient and then cooling and solidifying the mixture to form microspheres.

Microsphere-based compositions have been created and sold for a wide range of uses, including materials science, medicine delivery, cosmetics, and diagnostics. Microspheres are used in these formulations to provide targeted delivery, controlled release, and improved product performance (Rickerby et.al., 2007).

Here are a few examples of microsphere-based marketed preparations:

Zoladex (Goserelin Acetate Microspheres): This is a hormone therapy used to treat prostate cancer, breast cancer, and endometriosis. It consists of goserelin acetate microspheres that release the drug over a specified period, providing continuous suppression of hormone production.

Risperdal Consta (Risperidone Microspheres): It is an antipsychotic medication used to treat schizophrenia and bipolar disorder. It utilizes risperidone microspheres for long-acting injectable delivery, offering prolonged drug release.

Solid lipid nanoparticles:

This method was created in the 1990s. It is a type of colloidal carrier designed specially to transport lipophilic substances. The two different methods used to make it are homogenization and heated micro-emulsion. Solid lipid nanoparticles with a mean average size between 50 and 1000 nm. The fundamental component of the solid lipid nanoparticles, lipid matrix, solidifies at room temperature as well as at body temperature (Hou et.al., 2003). The principal attributes of solid nanoparticles of lipid (SLNs) with respect to parenteral administration are their remarkable physical stability and ability to halt the deterioration of integrated labile medications. It ought to be made with lipid and surfactant selection in mind in order to cross the blood-brain barrier. When developing SLNs, a number of methods are employed to ensure that the necessary features include:

a. High Pressure Homogenization method:

One of among the most popular techniques for preparing SLNs is this one. Lipids melt to form a liquid lipid phase, in which the medication dissolves or diffuses. The lipid-drug composition is blended with a stabilizer in a water-based phase to form an O/W emulsion (Biswas et.al., 2004).

High-pressure homogenization is applied to the emulsion in order to achieve nanoscale particles and lower droplet size.

Solid lipid nanoparticles are created when the lipid emulsion cools down or solidifies.

b. Hot Homogenization method:

Similar to high-pressure homogenization, this method involves emulsification of a lipid melt containing the drug in an aqueous phase.

The emulsion is then homogenized at an elevated temperature.

Subsequent cooling leads to solidification and formation of SLNs.

c. Supercritical Fluid technology:

Supercritical carbon dioxide is used as a solvent to dissolve lipids and the drug.

The mixture is then rapidly depressurized to form SLNs as the supercritical fluid rapidly transforms into a gas, leaving behind solid nanoparticles.

Several marketed preparations of SLNs i.e. Solid Lipid Nanoparticles have been developed for various applications in drug delivery, cosmetics, and other industries. These formulations utilize the advantages of SLNs, such as controlled release, enhanced stability, and improved bioavailability, to deliver therapeutic agents and enhance product performance (Anton et.al., 2008). Here are a few examples of SLN-based marketed preparations:

Emend (Aprepitant SLN formulation): It is used in chemotherapy-induced nausea and vomiting. It contains an aprepitant SLN formulation that enhances the bioavailability of the drug.

Arestin (Minocycline SLN formulation): It is a localized antibiotic treatment used in periodontal disease. It contains minocycline-loaded SLNs for targeted drug delivery to periodontal pockets.

Nanosuspensions:

A colloidal dispersion of solid particles smaller than one micron (nanoparticles) in a liquid media, usually water, is called a nanosuspension. Drugs that are poorly soluble in water can

have their solubility, bioavailability, as well as controlled release improved by using nanosuspensions. Nanoparticles in nanosuspensions have a large surface area and a tiny particle size, which improves medication solubility rates and therapeutic efficacy (Silva et.al., 2004).

Here's an overview of nanosuspensions and their preparation methods:

a. Media Milling:

It is a commonly used method for preparing nanosuspensions.

Drug particles are suspended in a liquid medium along with grinding beads.

The mixture is subjected to mechanical agitation or milling, causing the drug particles to be ground down to nanoscale sizes.

The size reduction is achieved by the collisions between the grinding beads and drug particles.

b. Antisolvent Precipitation:

This technique involves dissolving the drug into a solvent and then rapidly mixing it with an anti-solvent or a nonsolvent.

The rapid change in solvent conditions leads to formation of precipitate of drug particles in nanoscale sizes.

c. Salting out method:

In the salting-out method, drug particles are precipitated from a solution by adding a salt solution.

The salt disrupts the solubility of the drug, leading to particle precipitation in the nanoscale range.

A number of formulations based on nanosuspension have been created and put on the market to improve the solubility, bioavailability, as well as therapeutic effectiveness of medications that are not very soluble in water (De Campos et.al.,2001). These formulations address issues with drug absorption and dissolution by using nanosuspensions.

Here are a few examples of nanosuspension-based marketed preparations:

Tricor (Fenofibrate Nanosuspension): This is used to treat high cholesterol and triglyceride levels. It contains a fenofibrate nanosuspension that enhances the dissolution rate and bioavailability of the drug.

Rapamune (Sirolimus Nanosuspension): This is an immunosuppressive drug used in organ transplantation. It utilizes a sirolimus nanosuspension to improve drug solubility and enhance bioavailability.

Meritsof Nanotechnology based Dosage Forms:

Nanotechnology-based dosage forms offer a range of advantages that contribute to improved drug delivery, enhanced therapeutic outcomes, and novel applications. These advantages stem from the unique properties and capabilities of nanoparticles and nanomaterials.

Enhanced drug solubility and bioavailability: Nanoparticles can significantly enhance the solubility of poorly water-soluble drugs, leading to improved drug dissolution and better bioavailability.

Controlled and targeted drug delivery: Drugs can be controlled to release from nanoparticles, resulting in longer-lasting therapeutic benefits and fewer dose intervals. By limiting off-target effects, functionalization of nanoparticles enables tailored medication delivery to particular cells, tissues, or organs.

Improved Pharmacokinetics: Nanoparticles can modify drug distribution, metabolism, and elimination, leading to optimized pharmacokinetic profiles and improved drug half-lives.
Reduced side effects: By targeting drugs to specific sites and avoiding systemic circulation, nanotechnology-based dosage forms can reduce systemic side effects and toxicity.
Overcoming biological barriers: Due to their ability to cross biological barriers including the blood-brain barrier and mucosal barriers, drugs can now be delivered to previously unreachable locations.
Enhanced Intracellular delivery: Nanoparticles can facilitate the administration of drugs and therapeutic agents into cells, making them effective for intracellular targets.
Combination therapy: Nanoparticles can carry multiple drugs or therapeutic agents with different mechanisms of action, enabling synergistic combination therapies.
Improved drug stability: Nanoparticles can protect sensitive drugs from degradation, improving their stability during storage and administration.
Minimized first pass metabolism: Nanoparticles can bypass first-pass metabolism in the liver, leading to higher drug concentrations reaching the systemic circulation.
Novel formulations and applications: Nanotechnology enables the creation of novel dosage forms, including nanoparticles, liposomes, micelles, and more, expanding the possibilities for drug delivery.
Enhanced Therapeutics: Nanoparticles can serve as both therapeutic agents and diagnostic tools (therapeutics), allowing for real-time monitoring of treatment response.
Improved patient compliance: Nanotechnology-based dosage forms can reduce dosing frequency and improve patient compliance due to extended drug release and enhanced therapeutic effects.
Reduced environmental impact: Nanotechnology-based dosage forms can minimize drug waste, reduce the need for high drug doses, and decrease the environmental burden of pharmaceuticals.
These advantages highlight the potential of nanotechnology to revolutionize drug delivery and improve patient care across various medical fields. However, it's important to note that while nanotechnology-based dosage forms offer many benefits, careful consideration of formulation, safety, regulatory aspects, and ethical concerns is essential during their development and application.

Approachesof Nanotechnology based Dosage Forms:

Dosage forms based on nanotechnology have several uses in a variety of industries, particularly in the medical field. These uses make use of the special qualities of nanoparticles as well as nanomaterials to improve drug delivery, boost therapeutic results, and make new treatments possible.
Here are certain key applications of nanotechnology-based dosage forms:
Drug delivery: Drugs can be encapsulated in nanoparticles and delivered to specific body locations with regulated release kinetics. Oral, injectable, topical, & inhalation methods are included in this. medication effectiveness is increased and systemic side effects are decreased with targeted medication delivery (Desimone et.al., 2010).
Cancer treatment: Nanotechnology enables targeted drug delivery to cancer cells while sparing healthy tissues. Nanoparticles can carry chemotherapy drugs, targeted therapies, or imaging agents for early cancer detection.

Gene Therapy: For the purpose of gene therapy, target cells can receive genetic material such as DNA or RNA through nanoparticle delivery. This strategy has potential for molecular treatment of a number of diseases, including hereditary abnormalities.
Vaccines: Nanoparticle-based vaccine formulations can enhance immune response and provide controlled release of antigens. They are being explored for infectious diseases and cancer immunotherapies.
Neurological disorders: Nanoparticles can cross the blood-brain barrier to administer the drugs to the central nervous system. They are investigated for treating neurodegenerative diseases and brain tumours (Uner et.al., 2007).
Antibacterial applications: Nanoparticles can be used to administer antibiotics and enhance their efficacy against drug-resistant bacteria. They also have potential in wound healing and infection control.
Cardiovascular therapeutics: Nanoparticles can deliver drugs to target cardiovascular diseases and enhance the repair of damaged tissues.
Opthalmic applications: Nanoparticles are explored for targeted drug delivery to the eye, improving treatment for conditions like age-related macular degeneration and glaucoma.
Skin care cosmetics: Nanoparticles can enhance the delivery of active ingredients in skincare products, improving their effectiveness. They can also provide UV protection and anti-aging benefits.
Nutraceuticals: Nanotechnology enables enhanced delivery of vitamins, antioxidants, and other bioactive compounds in nutraceutical products.
Pulmonary delivery: Nanoparticles can be engineered for efficient drug delivery to the lungs, making them useful for respiratory diseases.
Implantable devices: Nanotechnology can improve the biocompatibility and working of implantable medical devices.
Regenerative medicine: Nanomaterials can be employed to engineer scaffolds and promote tissue regeneration in regenerative medicine applications (Sahaym et.al., 2008).
These applications demonstrate the versatility and potential of nanotechnology-based dosage forms to revolutionize various fields and improve patient care, product performance, and sustainability. However, it's important to ensure safety, regulatory compliance, and ethical considerations when developing and using nanotechnology-based products.

Conclusion

In conclusion, the application of nanotechnology in pharmacy has guideda new era of innovation and possibilities in drug delivery, diagnostics, and therapeutics. This extensive review has highlighted the significant advancements and diverse applications of nanotechnology-based dosage form, including nanoparticles, liposomes, solid lipid nanoparticles, and nanosuspensions. Long-standing issues in the pharmaceutical sector, such as insufficient drug solubility, restricted bioavailability, and uncontrolled medication release, have found answers in nanotechnology. Researchers and pharmaceutical experts have improved drug delivery efficiency, optimized therapeutic outcomes, and developed novel treatment options by carefully creating and manipulating nanoparticles.
The review has emphasized the advantages of nanotechnology-based dosage forms, including enhanced drug solubility and bioavailability, controlled and targeted drug delivery, improved pharmacokinetics, reduced adverse effects, and the potential for personalized medicine.

These advantages hold the promise of transforming patient care, optimizing treatment regimens, and improving patient compliance. In essence, the review underscores that nanotechnology in pharmacy has moved beyond theoretical concepts to practical applications that are changing the landscape of medicine and healthcare. The convergence of nanotechnology, pharmaceutical sciences, and medical research offers a promising path toward more effective treatments, improved patient outcomes, and a brighter future for healthcare innovation. As the field continues to progress, collaboration between researchers, healthcare professionals, and regulatory bodies will be paramount in harnessing the power of nanotechnology to its fullest extent and benefiting humanity as a whole.

Future scope of Nanotechnology: -

In the future, nanotechnology has the potential to completely transform healthcare and medicine. The following are some important fields where nanotechnology is anticipated to have a big impact:

Targeted drug delivery:

Targeted drug distribution is one of the most exciting uses of nanotechnology in medicine. Drugs can be specifically delivered to targeted cells or tissues using nanoparticle engineering, which minimizes side effects and boosts effectiveness. Targeting cancer cells, precisely delivering therapeutic chemicals, and minimizing harm to healthy tissue are all possible using functionalized nanoparticles.

Diagnostic imaging:

High levels of specificity and sensitivity are provided by contrast agents & imaging probes based on nanotechnology for medical imaging modalities as computed tomography (CT), ultrasound, and magnetic resonance imaging (MRI). These nanomaterials make it possible to diagnose diseases like cancer, cardiovascular issues, and neurological disorders earlier and with greater accuracy (Caruthers et.al., 2007).

Therapeutics:

Innovative therapeutic approaches, such gene therapy as well as RNA interference (RNAi), for the treatment of cancer, infectious diseases, and genetic abnormalities are made possible by nanotechnology. Nucleic acids, proteins, or other tiny molecules can be effectively delivered to target cells using nanoparticles, which can then modify gene expression or impede the progression of disease.

Regenerative medicine:

Because it makes tissue creation and regeneration easier, nanotechnology is essential to regenerative medicine. Damaged tissues and organs can regenerate thanks to nanoscale scaffolds and biomaterials, which offer structural support and signals for cell development and differentiation. To aid in tissue repair, growth factors along with signalling molecules can also be delivered via nanoparticles.

Point of care diagnostics:

Nanotechnology-based miniature diagnostic tools and biosensors make it possible to quickly and accurately identify biomarkers for a variety of ailments at the point of care. Particularly in situations with limited resources, these affordable and portable gadgets have an opportunity to enhance healthcare outcomes and accessibility(Petros et.al., 2010).

Theranostics:

Theranostic nanoparticles enable personalized therapy and real-time treatment response monitoring by combining diagnostic and therapeutic capabilities into a single platform. Targeted therapy guided by imaging feedback is made possible by these multifunctional nanoparticles that can carry therapeutic drugs and imaging probes at the same time.

Implantable diseases:

Biocompatibility and performance of implantable medical devices, like biosensors, stents, and prosthesis, are improved by nanotechnology. Implant longevity and functionality are increased by tissue integration and inflammation reduction provided by nanostructured surfaces. Additionally, by preventing bacterial adhesion, nanocoatings lower the chance of infection.

Drug resistance and Nanotherapeutics:

A major problem in medicine today is medication resistance, to which nanotechnology provides creative answers. Drug resistance pathways can be circumvented by nanoformulations through enhanced drug solubility, stability, & cellular uptake. Combination treatments that make use of drug delivery methods based on nanoparticles have the potential to overcome resistance in infectious illnesses and cancer.

Personalized medicine:

Personalized medicine techniques that are based on a patient's genetic composition, illness features, and response to treatment can be developed thanks to nanotechnology. Drug delivery systems based on nanoparticles can be tailored to deliver exact dosages of treatments to specific cells or tissues, maximizing therapeutic success while reducing side effects (De Campos et.al., 2001).

Funding:

This review article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Anton, N., Benoit, J. P., & Saulnier, P. (2008). Design and production of nanoparticles formulated from nano-emulsion templates—A review. *Journal of controlled release*, *128*(3), 185-199.

Babatunde, D. E., Denwigwe, I. H., Babatunde, O. M., Gbadamosi, S. L., Babalola, I. P., & Agboola, O. (2019). Environmental and societal impact of nanotechnology. *IEEE Access*, *8*, 4640-4667.

Biswas, A. K., Islam, M. R., Choudhury, Z. S., Mostafa, A., & Kadir, M. F. (2014). Nanotechnology based approaches in cancer therapeutics. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, *5*(4), 043001.

Biswas, A. K., Islam, M. R., Choudhury, Z. S., Mostafa, A., & Kadir, M. F. (2014). Nanotechnology based approaches in cancer therapeutics. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, *5*(4), 043001.

Carla, A. H. (2005). Dendritic supramolecular assemblies for drug delivery. *Chemical communications*, (34), 4309-4311.

Caruthers, S. D., Wickline, S. A., & Lanza, G. M. (2007). Nanotechnological applications in medicine. *Current opinion in Biotechnology*, *18*(1), 26-30.

Caster, J. M., Patel, A. N., Zhang, T., & Wang, A. (2017). Investigational nanomedicines in 2016: a review of nanotherapeutics currently undergoing clinical trials. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *9*(1), e1416.
Chang, C. H., Huang, W. Y., Lai, C. H., Hsu, Y. M., Yao, Y. H., Chen, T. Y., ... & Lin, Y. H. (2011). Development of novel nanoparticles shelled with heparin for berberine delivery to treat Helicobacter pylori. *Acta biomaterialia*, *7*(2), 593-603.
Cheon, J., & Lee, J. H. (2008). Synergistically integrated nanoparticles as multimodal probes for nanobiotechnology. *Accounts of chemical research*, *41*(12), 1630-1640.
Das, S., & Suresh, P. K. (2011). Nanosuspension: a new vehicle for the improvement of the delivery of drugs to the ocular surface. Application to amphotericin B. *Nanomedicine: Nanotechnology, Biology and Medicine*, *7*(2), 242-247.

Debbage, P., & Jaschke, W. (2008). Molecular imaging with nanoparticles: giant roles for dwarf actors. *Histochemistry and cell biology*, *130*, 845-875.
Devasena, T., & Devasena, T. (2017). Diagnostic and therapeutic nanomaterials. *Therapeutic and diagnostic nanomaterials*, 1-13.
Drexler, E. (1987). *Engines of creation: The coming era of nanotechnology*. Anchor.
Du, J., Li, X., Zhao, H., Zhou, Y., Wang, L., Tian, S., & Wang, Y. (2015). Nanosuspensions of poorly water-soluble drugs prepared by bottom-up technologies. *International journal of pharmaceutics*, *495*(2), 738-749.
Hou, D., Xie, C., Huang, K., & Zhu, C. (2003). The production and characteristics of solid lipid nanoparticles (SLNs). *Biomaterials*, *24*(10), 1781-1785.
Jain, N., Jain, R., Thakur, N., Gupta, B. P., Jain, D. K., Banveer, J., & Jain, S. (2010). Nanotechnology: a safe and effective drug delivery system. *Asian Journal of Pharmaceutical and Clinical Research*, *3*(3), 159-165.
JuQun, X. I., & Rong, G. (2007). Studies on molecular interactions between puerarin and PC liposomes. *Chinese science bulletin*, *52*(19), 2612-2617.
Kakade, T., Kadam, V., Dhanavade, K., & Salunkhe, V. (2013). A review on pharmaceutical nanotechnology: Dendrimers. *World J Pharm Pharm Sci*, *2*, 4815-4830.
Logothetidis, S. (2011). Nanomedicine: the medicine of tomorrow. In *Nanomedicine and Nanobiotechnology* (pp. 1-26). Berlin, Heidelberg: Springer Berlin Heidelberg.
Mashaghi, S., Jadidi, T., Koenderink, G., & Mashaghi, A. (2013). Lipid nanotechnology. *International journal of molecular sciences*, *14*(2), 4242-4282.
Medina, C., Santos-Martinez, M. J., Radomski, A., Corrigan, O. I., & Radomski, M. W. (2007). Nanoparticles: pharmacological and toxicological significance. *British journal of pharmacology*, *150*(5), 552-558.
Müller, R. H., Mäder, K., & Gohla, S. (2000). Solid lipid nanoparticles (SLN) for controlled drug delivery–a review of the state of the art. *European journal of pharmaceutics and biopharmaceutics*, *50*(1), 161-177.
Noebe, R. (1997). Nanosystems Molecular Machinery, Manufacturing, and Computation Edited by K. Eric Drexler. *MATERIAL AND MANUFACTURING PROCESS*, *12*(1), 160-162.
Ochekpe, N. A., Olorunfemi, P. O., & Ngwuluka, N. C. (2009). Nanotechnology and drug delivery part 1: background and applications. *Tropical journal of pharmaceutical research*, *8*(3).
Petros, R. A., & DeSimone, J. M. (2010). Strategies in the design of nanoparticles for therapeutic applications. *Nature reviews Drug discovery*, *9*(8), 615-627.

Prabhu, N., Raj, D. T., Yamuna, G. K., Ayisha, S. S., Puspha, J., & Innocent, D. (2010). Synthesis of silver phyto nanoparticles and their antibacterial efficacy. *Digest Journal of Nanomaterials & Biostructures (DJNB)*, *5*(1).
Rickerby, D. G., & Morrison, M. (2007). Nanotechnology and the environment: A European perspective. *Science and Technology of Advanced Materials*, *8*(1-2), 19.
Rickerby, D. G., & Morrison, M. (2007). Nanotechnology and the environment: A European perspective. *Science and Technology of Advanced Materials*, *8*(1-2), 19.
Rizzo, L. Y., Theek, B., Storm, G., Kiessling, F., & Lammers, T. (2013). Recent progress in nanomedicine: therapeutic, diagnostic and theranostic applications. *Current opinion in biotechnology*, *24*(6), 1159-1166.
Sahaym, U., & Norton, M. G. (2008). Advances in the application of nanotechnology in enabling a 'hydrogen economy'. *Journal of Materials Science*, *43*(16), 5395-5429.
Sahaym, U., & Norton, M. G. (2008). Advances in the application of nanotechnology in enabling a 'hydrogen economy'. *Journal of Materials Science*, *43*(16), 5395-5429.
Semalty, A., Semalty, M., Rawat, M. S. M., & Franceschi, F. (2010). Supramolecular phospholipids–polyphenolics interactions: The PHYTOSOME® strategy to improve the bioavailability of phytochemicals. *Fitoterapia*, *81*(5), 306-314.
Shah, S., Famta, P., Bagasariya, D., Charankumar, K., Amulya, E., Khatri, D. K., ... & Srivastava, S. (2022). Nanotechnology based drug delivery systems: Does shape really matter?. *International Journal of Pharmaceutics*, *625*, 122101.
Shew, A. (2013). Engines of Second Creation: Stories About Nanotechnology. *Bulletin of Science, Technology & Society*, *33*(1-2), 21-27.
Silva, G. A. (2004). Introduction to nanotechnology and its applications to medicine. *Surgical neurology*, *61*(3), 216-220.
Sim, S., & Wong, N. K. (2021). Nanotechnology and its use in imaging and drug delivery (review). Biomed Rep 14 (5): 42. https://doi.org/10.3892/br.2021.1418.
Stander, L., & Theodore, L. (2011). Environmental implications of nanotechnology—an update. *International journal of environmental research and public health*, *8*(2), 470-479.
Tibbals, H. F. (2017). *Medical nanotechnology and nanomedicine*. Crc Press.
Trotta, M., Debernardi, F., & Caputo, O. (2003). Preparation of solid lipid nanoparticles by a solvent emulsification–diffusion technique. *International journal of pharmaceutics*, *257*(1-2), 153-160.
Üner, M., & Yener, G. (2007). Importance of solid lipid nanoparticles (SLN) in various administration routes and future perspectives. *International journal of nanomedicine*, *2*(3), 289-300.
Vemuri, S., & Rhodes, C. T. (1995). Preparation and characterization of liposomes as therapeutic delivery systems: a review. *Pharmaceutica acta helvetiae*, *70*(2), 95-111.
Wickline, S. A., & Lanza, G. M. (2003). Nanotechnology for molecular imaging and targeted therapy. *Circulation*, *107*(8), 1092-1095.
Wilczewska, A. Z., Niemirowicz, K., Markiewicz, K. H., & Car, H. (2012). Nanoparticles as drug delivery systems. *Pharmacological reports*, *64*(5), 1020-1037.
Yetisgin, A. A., Cetinel, S., Zuvin, M., Kosar, A., & Kutlu, O. (2020). Therapeutic nanoparticles and their targeted delivery applications. *Molecules*, *25*(9), 2193)