REVIEW ARTICLE

Applicability of Vesicular Formulation in the Delivery of Hydrophobic Drugs

Gunjan Chaudhari*, Molika Malpani, Umesh B. Telrandhe

Department of Pharmacognosy, Datta Meghe College of Pharmacy, Datta Meghe Institute of Higher Education and Research (DU), Wardha, Maharashtra, India

Abstract

The delivery of hydrophobic drugs has posed significant challenges in the field of pharmaceuticals due to their poor aqueous solubility and low bioavailability. Vesicular formulations, such as transferosomes and liposomes, have shown promise as effective medication delivery methods to address these issues. The application of vesicular formulations in improving the solubility, stability, and targeted delivery of hydrophobic medicines is summarized in this abstract. Because of their special bilayer structure, vesicular carriers can encapsulate hydrophobic medicines in their lipid or surfactant membranes, improving their solubility and bioavailability. Furthermore, vehicles can hold a variety of pharmacological compounds due to their flexibility. Phospholipid bilayers form liposomes, which have been thoroughly studied and could transport either hydrophilic or hydrophobic medications. In addition, interesting platforms for drug packaging and delivery are biosomes, which are made of non-ionized and transferosomes, which contain edge activators. Modifying vesicles with ligands or antibodies that identify receptors on target cells or tissues can enable the targeted administration of hydrophobic medicines. As a result, there are fewer side effects and better therapeutic results due to targeted medication distribution. To sum up, the distribution of hydrophobic medicines can be achieved through the diverse and efficient use of vesicular formulations. They offer solutions for enhancing drug solubility, stability, and bioavailability, as well as enabling targeted and controlled drug release. The continued exploration of vesicular carriers in drug delivery systems holds great promise for improving the therapeutic efficacy of hydrophobic drugs and expanding the possibilities of pharmaceutical science.

Key words: Bioavailability, Dendrimers, Drug delivery system, Encapsulation, Liposomes, Micelles, Nanocarriers, Nano emulsions, Nano gels, Nanomedicine, Nanosensors, Nano toxicology, Nanotechnology, Therapeutic efficacy

INTRODUCTION

Previously, a few disorders were treated using medication delivery systems. To treat illnesses, all medications rely on substances with pharmacologic active metabolites. According to conventional wisdom and methods, most modern medications are made from herbs. Today's key pharmaceutical chemicals and their derivatives are derived from roughly 25% of the natural resource.[1] The uses of nanomaterials were for their mechanical, optical, electrical, conductive, chemical in nature, and physiological applications; more recently; however, attention has turned to their potential for use in medicine, particularly in the field of delivering drugs.[2] This is because employing massive amounts of polymers for the administration of medications presents challenges, such as inadequate tolerability, *in vivo* security, the ability to dissolve, gastrointestinal absorption, perpetuated and specific transport to the site of action, effectiveness in therapy, all-encompassing side effects, and drug plasma fluctuations. Unquestionably gained from the use of nanostructures as the most common technique for medicine delivery.[3] According to gadgets, drugs can now be given exactly to certain bodily areas. Using technology, it is possible to bypass the liver and administer medications that are not highly water soluble. Because of technology and to avoid the liver, which would otherwise allow for first-pass metabolism to occur.[4] Drugs made using nanotechnology have these may remain in the

Address for correspondence:
Gunjan Chaudhari, Department of Pharmacognosy, Datta Meghe College of Pharmacy, Datta Meghe Institute of Higher Education and Research (DU), Wardha, Maharashtra, India.
E-mail: gunjanchaudhari081@gmail.com

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lengthy periods of time and possess specialized delivery mechanisms including soaking endocytosis, they have a higher oral bioavailability. According to reports, the uptake of nanostructures is 15–250 times larger than that of 1–10 µm microparticles.[5] The more difficult traditional medications are used for the management and treatment of chronic conditions, such as asthma, lung cancer, high blood pressure, HIV, and insulin.

The delivery of hydrophobic drugs presents a significant challenge in the field of pharmaceuticals and drug development. When it comes to successful distribution within the body, hydrophobic drugs – often distinguished by their poor solubility in aquatic environments-face numerous challenges.[6] Using vesicular formulations is one possible way to get around these obstacles. A type of drug delivery method known as vesicular formulations encapsulates medications in lipid or phospholipid bilayers to create vesicles. Depending on their unique makeup and properties, these vesicles can be categorized as liposomes, biosomes, or ectosomes, among other forms. Because of their adaptability and distinctive qualities, vehicles are especially well-suited for the administration of hydrophobic medications [7] which is shown in Figure 1.

THE MEDICINE DELIVERY DEVICE BASED ON NANOTECHNOLOGY

A significant breakthrough in the realm of healthcare is a medication delivery system built on nanotechnology. With the help of this innovative technique, medication administration will be transformed by the special qualities of nanomaterials.[8] Fundamentally, the apparatus is made up of nanoscale structures or particles that could encapsulate and deliver drugs to target locations inside the organism. Because of the accuracy with which these nanocarriers are made, medications can be precisely released at the intended site, maximizing therapeutic efficacy, and reducing adverse effects.[9] This gadget, which is based on nanotechnology, has the advantage of being able to transport medications to previously inaccessible locations by overcoming biological barriers. For example, it can cross the blood–brain barrier to treat neurological conditions or precisely navigate the circulation to fight cancer cells,[10] which is shown in Figure 2.

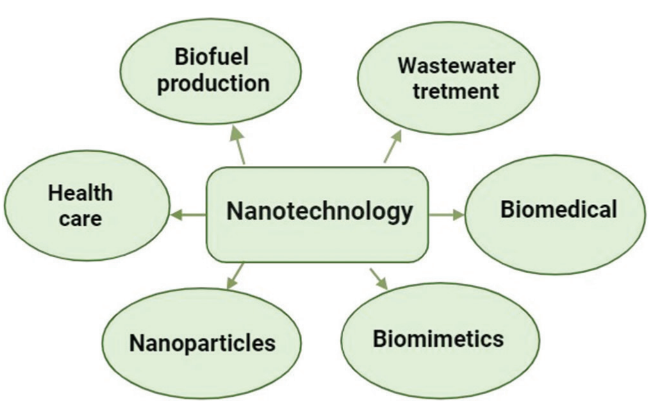

Figure 1: Nanotechnology includes some factors

This technology may decrease the frequency of medication administration, improving patient compliance and quality of life in addition to improving patient care. Its potential applications extend to various medical fields, from chronic disease management to targeted therapies, ushering in a new era of healthcare that is more effective, precise, and patient-centric. The development of a medicine delivery device based on nanotechnology holds the promise of transforming the way we approach healthcare, making treatments more efficient, minimally invasive, and tailored to individual needs.[11]

Fundamentals of nanotechnology-based drug design techniques

The branch of healthcare known as quantum medicine, materials with nanoscale dimensions are used for the prevention and implementation of a variety of disorders. For example, nanoparticles that are biocompatible are Nanorobots that can be used for a variety of purposes in living organisms, including diagnosis, administration, sensing, and actuation.[12] The method for delivering drugs might be modified to use nanotechnology to get rid of all these limitations. The latest technology is being used in the field of nanoparticle applications due to the advantages it may contain the ability to alter properties, such as the immune system, dissolution, drug absorption trends, diffusion coefficients, and usability.[13]

Drug delivery process

Nanotechnology has transformed the way drugs are delivered by providing targeted and controlled drug release, increasing efficiency, and decreasing negative effects. A guide to an outline regarding how nanotechnology is used in the medicine delivery process.

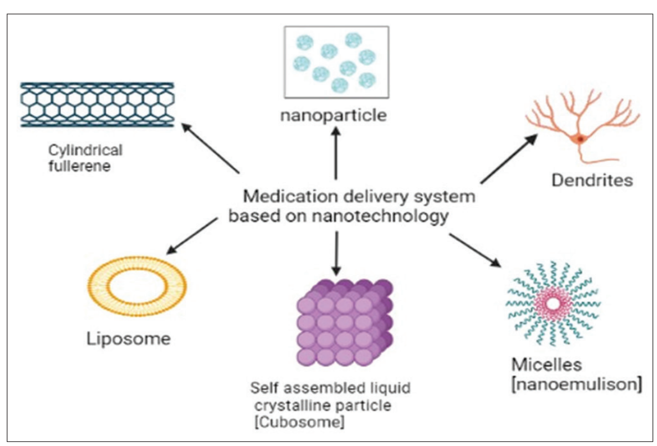

Figure 2: Delivery device based on nanotechnology

The process of delivering medicinal chemicals to the body to produce the intended pharmacological effect is known as drug delivery. It includes several crucial processes, the first of which is the formulation of the medication in an appropriate delivery format, including tablets, injections, or creams. The medicine must be absorbed into the bloodstream after being supplied through one of several methods, such as oral intake, injection, or topical application, for it to reach its target site.[14] The rate and degree of absorption depend on the formulation and mode of administration. The medication then travels throughout the body through the circulatory system and may gather tissues. The drug's chemical structure and potency may change because of metabolism, which is followed by excretion from the body through the kidneys or liver. Optimizing drug delivery systems is essential to enhance therapeutic outcomes, reduce side effects, and improve patient compliance, with ongoing advancements in technologies, such as nanotechnology and targeted drug delivery aiming to make this process more efficient and precise.[15]

Here are the fundamental aspects of how nanotechnology facilitates the drug delivery process

Nanoparticle formulation

Core-shell structures

Nanoparticles can have a core (e.g., drug payload) and a shell (e.g., lipid, polymer) that controls drug release and protects the payload. Core-shell structures consist of a central core enclosed by an outer shell, finding versatile applications. They enhance drug delivery by encapsulating hydrophobic drugs, improve catalytic activity, boost nanoelectronics device performance, and enable the creation of advanced composite materials, offering tailored material properties for a wide range of applications.[16]

Controlled drug release

PH or temperature responsiveness

External stimuli: Drug release can be triggered using external stimuli, such as light, ultrasound, or magnetic fields. External stimuli in drug delivery involve using factors, such as light, temperature, or magnetic fields to trigger controlled drug release. These stimuli-responsive systems can be remotely activated, allowing precise, on-demand drug delivery to specific sites, enhancing therapeutic outcomes, and reducing side effects, making them valuable in various medical applications.[17]

Enzyme-responsive systems: Nanoparticles release drugs in the presence of specific enzymes present in certain tissues. According to reports, drug delivery systems release medication in response to specific enzymes in the body that are often associated with diseases. With its controlled and focused drug release, this method maximizes therapeutic precision and reduces side effects. It is useful in managing inflammation and treating cancer, for example, and enhances the effectiveness of treatment.[18]

Targeted drug delivery

Passive targeting

Accumulates nanoparticles in tumor tissues with leaky vasculature by using the increased permeability and retention effect. Using elements, such as leaky blood arteries, passive targeting in drug delivery makes use of the natural qualities of drug carriers to accumulate in target tissues, such as cancer. This method reduces side effects without requiring molecular interactions by improving drug transport to targeted areas and improving therapeutic efficacy while minimizing exposure to healthy tissues.[19]

Active targeting

Involves the precise delivery of drugs by the binding of ligands (such as peptides or antibodies) on the surface of nanoparticles to receptors on target cells. Using ligands or molecules on the surface of drug carriers to engage with certain receptors or biomolecules found in the target tissue or cells is known as active targeting in drug delivery. By enhancing therapeutic efficacy and decreasing off-target effects, this exact interaction enables the selective delivery of medications to the desired location. Active targeting allows for a more individualized and focused approach to drug delivery, especially for treating conditions, such as cancer.[20]

Biocompatibility and safety

Surface modification

Surface engineering to extend circulation time, lower immunogenicity, and improve biocompatibility. To improve biocompatibility and safety in medical devices and materials, surface modification is essential. The materials can be made safer and more appropriate for biomedical applications by modifying their surface characteristics, such as charge, hydrophobicity, or the inclusion of bioactive coatings, which can also promote tissue integration and lessen immunological responses. Surface alterations can further improve the materials' compatibility with biological systems by enabling regulated medication release and preventing hazardous interactions.[21]

Biodegradable materials

Utilizing substances that are easily removed from the body and biodegradable. To guarantee biocompatibility and safety in medical applications, biodegradable materials are essential. The body can naturally break down these compounds without injury or toxicity. Their application in tissue engineering, drug delivery systems, and medical implants lowers the chance of chronic foreign body reactions and the requirement for removal surgeries. Biodegradable materials are useful for a variety of medical devices and therapies because they minimize side effects and increase patient safety.[22]

Diffusion

The process by which molecules migrate over a semipermeable membrane from a sector of higher concentration to one of lower concentration along a concentration gradient is called diffusion. The spontaneous transfer of particles from a region of higher concentration to a region of lower concentration, leading to the equalization of concentration, is known as diffusion and is a fundamental phenomenon in nature. It happens in a variety of systems, including gases, liquids, and biological tissues. It is a passive, ongoing process. Diffusion occurs at the molecular level because of the random movement of particles, such as atoms, molecules, and ions. These particles travel in all directions, crashing into one another, and eventually spreading out to evenly occupy the available space. Diffusion is an essential component of many biological processes, such as the dissolution of compounds in solvents, the transfer of nutrients within cells, and the exchange of gases in the respiratory system. Fick's laws of diffusion provide mathematical descriptions of diffusion processes, helping to predict the rate at which substances will disperse in each medium.[23]

DDS has unique morphological, chemical, and physical properties that may make them more receptive to certain drug polarities due to chemical interactions.[24] The release of pharmaceuticals in Nanocarriers which modeled by several different methods, including diffuse, financially sound, substance, and stimulus-controlled release. Drugs are of various types in nature, which is shown in Figure 3.

DRUG DELIVERY USING NANOTECHNOLOGY-BASED UPON NATURAL PRODUCTS

Nanotechnology and natural product-based drug delivery systems are a potential example of science and nature coming together. By utilizing the special qualities of nanoscale materials and compounds sourced from natural sources, these inventive methods improve the safety, effectiveness, and selectivity of medication delivery. Natural goods are frequently employed as medicinal agents or as the building blocks for the creation of new drugs, such as plant extracts or compounds originating from biological sources. When combined with nanotechnology, they can solve a few drug delivery-related issues.[25] These natural products can be encapsulated by nanoparticles or Nanocarriers, which will shield them from deterioration and increase their solubility and bioavailability. In addition to allowing for controlled and long-term administration, this protective shield lowers the frequency of drug doses. Targeted drug distribution is made possible by nanotechnology. Functionalized nanoparticles can be engineered to recognize specific cells or tissues, ensuring that the drug is delivered precisely where needed while minimizing exposure to healthy cells. This targeted approach reduces side effects and enhances therapeutic outcomes. Furthermore, natural products can serve as green alternatives to synthetic materials, reducing environmental impact and potential toxicity associated with drug carriers. These natural-based nanosystems are biocompatible and biodegradable, promoting sustainability in drug delivery.[26]

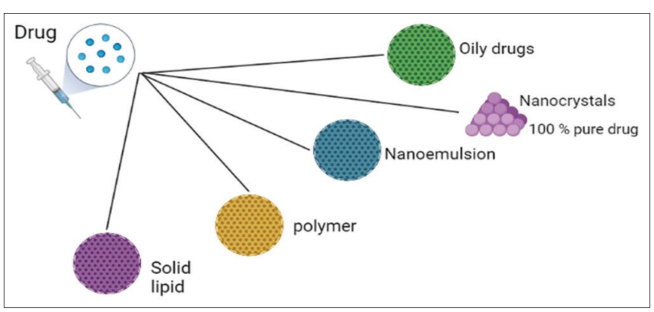

Figure 3: Nanotechnology depends upon DDS

According to research by the (World Health Organization), some traditional medicine provides for the fundamental medical needs of 80% of the people in underdeveloped nations. At present, the scientific focus is on the various natural sources based on nanotechnology. Since a very long time, they continue to hold a wealth of nutrients for the development of novel, highly effective medications.[27]

Here's how, Nanotechnology is utilized with natural products in drug delivery:

Nanoparticle formulation with natural polymers

Natural polymers, such as chitosan, alginate, and gelatine are used to create nanoparticles through techniques such as nanoprecipitation or emulsification. These natural polymer-based nanoparticles serve as carriers for drugs. Nanoparticle formulation using natural polymers involves creating nanoparticles with biodegradable and biocompatible materials sourced from nature. Natural polymers such as chitosan, alginate, and cellulose are utilized to encapsulate drugs or deliver therapeutic agents. These formulations are advantageous for their safety, reduced toxicity, and potential for sustainable drug delivery systems, finding applications in pharmaceuticals, biomedicine, and tissue engineering.[28]

Encapsulation of natural extracts

Active compounds extracted from natural sources (e.g., phytochemicals, flavonoids, polyphenols) are encapsulated in nanoparticles to enhance their bioavailability and therapeutic potential. Encapsulation of natural extracts involves enclosing bioactive compounds from plant sources within protective carriers, such as liposomes or nanoparticles. This approach enhances the stability, bioavailability, and controlled release of these extracts. It's widely used in the food, pharmaceutical, and cosmetic industries to improve the delivery and effectiveness of natural ingredients in various products.[29]

Combination therapy with natural compounds

Nanotechnology allows for the co-delivery of multiple natural compounds or a combination of natural and synthetic drugs, creating synergistic effects and improving therapeutic outcomes. Combination therapy with natural compounds involves using multiple bioactive substances from natural sources to treat diseases synergistically. This approach harnesses the diverse therapeutic properties of these compounds, often with fewer side effects, to enhance treatment effectiveness in conditions, such as cancer, cardiovascular diseases, and infections, providing a holistic and well-tolerated approach to healthcare.[30]

Nano emulsions with natural surfactants

Nano emulsions use natural surfactants to stabilize drug-loaded Nano droplets. This approach improves drug solubility, facilitates absorption, and provides sustained drug release. Nano emulsions with natural surfactants are fine oil-in-water or water-in-oil dispersions stabilized by naturally derived surfactants. They find applications in food, pharmaceuticals, and cosmetics. These systems offer improved solubility, bioavailability, and controlled release of bioactive compounds while reducing the need for synthetic additives, making them more appealing for health-conscious consumers.[31]

Some Natural Plants which are used to treat disease:

i. Alzheimer's disease: The *Galanthus woronowii* Losinsk plant has an acetylcholinesterase inhibitor that can treat Alzheimer's disease.
ii. Cancer: *Taxus brevifolia* plant.
iii. Liver disease: Silymarin from *Silybum marianum*.

And their actions are shown in Figure 4.

Numerous natural chemicals have already been investigated and their composition and activities determined. Plants include a variety of bioactive chemicals including alkaloids, tannins, flavonoids, terpenes, saponins, steroids, and phenolic compounds.[32]

ACTION MECHANISM OF NANO DRUG DELIVERY SYSTEM

Nanoparticles offer advantageous qualities that can be employed to enhance medicine delivery when created to bypass the body's defense mechanisms. The effectiveness, safety, and tolerability of ingested drugs have been improved using various nanoparticle compositions in pharmacological research. The shape, surface electrical charge, and shape are important variables to consider when developing effective nanoscale delivery systems that function through a variety of methods.[33]

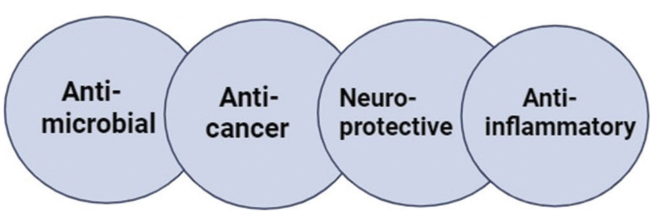

Figure 4: Biological compounds obtained from higher plants

APPLICATION OF NANOTECHNOLOGY

Nanotechnology is a multidisciplinary field focused on manipulating and utilizing matter at the nanoscale, typically between 1 and 100 nanometers. At this scale, materials exhibit unique properties, allowing precise engineering at the atomic and molecular levels. It involves designing, characterizing, and applying nanomaterials and devices, enabling innovation across various sectors, such as medicine, electronics, energy, and more. Applications range from targeted drug delivery and efficient electronics to sustainable energy solutions and environmental remediation. Nanotechnology's potential lies in its ability to revolutionize technologies, creating impactful advancements in diverse fields through the manipulation of matter on an incredibly small scale [Figure 5].[34]

THE EFFECTS OF NANOTECHNOLOGY

A broad digital infrastructure and a wide range of potential uses exist for nanotechnology. Nanotechnology allows for the manipulation of the fundamental atomic and molecular level of organization and defines the functioning of both biological organisms and man-made products. Because nanotechnology is multidisciplinary, it bucks the trend of academic specialization. As a result, it combines all academic fields, but mainly engineering, technology, and medicine. Self-assembling and top-down manufacturing techniques have been added to the industry's previously more bulk manufacturing abilities. Nanotechnology has affected research and development's pace and scope to the point where authorities now must consider. Have decided to invest in nanotechnology because of the wide range of uses

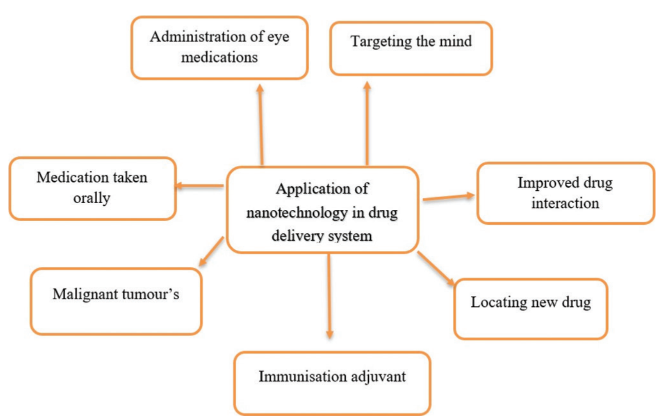

Figure 5: Application of nanotechnology

it has. At present, one of the key forces driving technical, economic transformation, and industrial competition is nanotechnology.[35]

Some of the effects of nanotechnology

Miniaturization

Allows for the creation of electronic components that are more compact and powerful while also being more effective. Faster Computers: By enabling the development of faster processors and memory components using Nanoelectronics, computing capabilities may be completely altered.

Stronger and lighter substances

Creating lightweight, high-strength materials helps the aerospace and automotive industries improve fuel economy and lessen their impact on the environment.

Building: Increases the resilience and sustainability of structures by strengthening and extending the durability of building materials.[36]

Environmental remediation

Cleanup of soil and water
Provides nanoscale remedies for environmental remediation that help remove pollutants from sources of soil and water.

Items for consumers. Nanotechnology aids in environmental remediation by improving soil and water cleanup. Nanoparticles and nanomaterials efficiently adsorb, break down, or immobilize contaminants, including heavy metals and pollutants. This approach offers effective and sustainable solutions for addressing environmental pollution, safeguarding ecosystems, and public health.[37]

Consumer products

Nano-coatings
These coatings offer consumer products self-cleaning, antibacterial, and Ultraviolet-protective surfaces, extending the life and safety of the product. Nano-coating's, ultra-thin layers of nanoparticles, are revolutionizing consumer products. These coatings provide enhanced durability, water-repellency, and resistance to stains and scratches. From self-cleaning windows to scratch-resistant phone screens, Nano-coatings improve the performance and longevity of a wide range of everyday items, offering convenience and cost-effective solutions.[38]

Consumption and agriculture

Food safety
Enables the creation of better packaging materials that increase food shelf life and cut down on food waste. In the realm of consumption and agriculture, food safety is paramount. Nanotechnology contributes by enabling improved food packaging and quality control. Nanosensors can detect contaminants, while Nano-coatings prevent spoilage and enhance shelf life. These innovations bolster food safety, reduce waste, and ensure the delivery of safe, high-quality products to consumers.

NANOMATERIALS USED IN DRUG DELIVERY SYSTEMS - THEIR TOXICOLOGY

Nanomaterials play a crucial role in drug delivery by precisely transporting therapeutic agents to targeted body sites. Despite their efficiency, concerns arise due to potential toxic effects. Nanoparticles, with their small size and high surface area, interact uniquely with biological systems, leading to concerns such as oxidative stress, inflammation, and cellular damage. Toxicological profiles vary based on nanomaterial type, size, surface properties, and exposure route. For instance, inhaled carbon nanotubes may induce lung inflammation, while metal nanoparticles, such as silver and gold can be cytotoxic. Stability issues and the potential release of toxic ions raise worries about long-term exposure.[39]

When compared to bulk materials, nanoparticles have special features that have a high surface-to-volume ratio to volume and their tiny size effect. They show toxicity, which is unexpected and not present with materials in large quantities. Nanoparticles are often smaller in size, between 100 and 10,000 times shorter than human cells, and equivalent to large molecules in biological systems, such as enzymes and receptors. Advanced ceramic materials, such as glass ceramic, have demonstrated toxicity to abnormal cells, such as cancer cells [Table 1].[40]

BENEFITS OF NANOTECHNOLOGY

Nanotechnology offers a diverse array of benefits across numerous fields, making it a transformative force in

Table 1: Toxicity of a few Nano-participant

Nanoparticle	Teat organ	Toxic effect
Silver nanoparticle	HUVECs (cells from the endothelium of the human umbilical vein).	Damage& failure of endothelial cells.
Zinc oxide nanoparticle	Cell line from a human lung cancer tumor.	Cell line lung adenocarcinoma in humans: cytotoxicity.
Titanium dioxide nanoparticle	Epithelial cells from the human stomach.	DNA oxidative stress and damage.

Table 2: Risks associated with nanotechnology

Risk category	Specific risks
Health and safety	Inhalation of nanoparticles leads to potential health risks. Skin exposure to hazardous nanomaterials. Uncertain long-term effects of nanomaterial exposure.
Environmental	Accidental release of nanoparticles into the environment. Impact on ecosystems and wildlife due to nanomaterials.
Ethical and social	Privacy concerns due to advanced nanosensors. Socioeconomic disparities in access and use. Ethical implications of human enhancement technologies.
Regulatory	Lack of standardized regulations for nanomaterials. Challenges in risk assessment and management.[47]

science and industry. In medicine, it has ushered in a new era of targeted drug delivery, improving treatment effectiveness while minimizing side effects. It also has advanced diagnostics with highly sensitive tools for early disease detection. Beyond healthcare, nanomaterials have boosted energy efficiency, leading to better batteries, solar cells, and fuel cells, thus reducing environmental impact.[41]

Nanotechnology revolutionizes water purification with advanced filters and membranes, ensuring access to safe drinking water. It enhances material properties, yielding stronger and lighter products in aerospace and construction. In electronics, nanomaterials enable smaller and more powerful devices, while environmental remediation benefits from their pollutant-cleaning capabilities. Lightweight and robust materials aid space exploration, and agriculture benefits from nano pesticides and improved nutrient delivery. These advancements highlight nanotechnology's potential to address global challenges, improve healthcare, and drive innovation. Responsible use and regulation are crucial to ensure its positive impact on society and the environment.[42]

Nanotechnology consists of more benefits:

- New, quicker computer kinds, more efficient power sources, and life-saving medical procedures are all possible thanks to nanotechnology.
- Availability of construction materials those are harder, stronger, and lighter.
- Better chronic disease monitoring, diagnosis, and treatment thanks to equipment and medication delivery systems development.
- Enhancements to transportation systems
- Inexpensive and clean energy.
- The emergence of new items and the enhancement of the present products.[43]

RISKS OF NANOTECHNOLOGY

In nanotechnology, nanoparticles are used, if nano particles have poor solubility, and then there is a high-risk factor for causing cancer. Nanoparticle toxicity is determined by its dimensions, form, surface properties, and inclination to agglomerate. A significant increase in contaminants, such as air and water contamination, has also been linked to nanotechnology. Nanoparticles also show toxicity because of their large surface area. It shows that small particles and larger surface areas consist of high risk; it may be positive or may be negative. Nanotechnology has a negative impact on people's health care. It also shows various types of side effects that may lead to cause cancer [Table 2].[44]

Nanotechnology, with its immense potential, brings forth a spectrum of inherent risks that require prudent management to ensure responsible progress. One prominent concern pertains to health and environmental ramifications, stemming from the small size of nanoparticles, which enables them to infiltrate biological barriers and potentially trigger toxic reactions when inhaled or ingested. Manufacturing nanomaterials may also pose hazards due to the involvement of toxic substances and energy-intensive processes, necessitating stringent safety measures.[45] Furthermore, the absence of comprehensive regulatory frameworks for nanomaterials raises doubts about their assessment and oversight. Ethical quandaries emerge concerning privacy, security, and societal disparities as nanotechnology finds applications in surveillance, data storage, and beyond. The rapid advancement of this field underscores the importance of equitable access to its benefits, while the complex nature of nanoscale systems can lead to unforeseen consequences, highlighting the need for ongoing research and vigilance. In addition, comprehending nano-bio interactions is pivotal, especially in the context of medical applications. To address these concerns, rigorous safety assessments, robust regulations, transparent research practices, and continual monitoring of environmental and health impacts are essential, with an interdisciplinary and precautionary approach being crucial to maximize the potential of nanotechnology while minimizing potential harm.[46]

METHODS (THE SEVERAL KINDS OF MEDICINAL NANOSYSTEMS FOUND IN NANOTECHNOLOGY)

Nanoshells

Nanoshells are modified drug delivery devices that have a metallic outermost layer and a silica-based center. By changing the proportion of the interior to the shell, these nanoparticles' properties can be altered. Creating these small structures with certain physical characteristics, such as size and morphological features, allows for specific functional properties. Because only a few of the compounds can be synthesized in the necessary morphological characteristics, nanoshells are employed to develop novel structures with a diversity of morphogenesis. To obtain the proper morphology, thin shells could be applied on particles of a particular shape. Since rare elements may be incorporated into affordable cores, these kinds of shells offer the benefit of being cheaper than 9. Immunological methods can be used to create nanoshells that are specifically targeted; one example of such a target is the creation of gold nanoshells that have antibodies attached to their outer gold surfaces to improve their ability to target malignant tumor cells.[48]

Carbon nanotubes

Carbon nanotubes are composed of carbon tubular constructions. The aforementioned tubes are composed of graphite cylindrical sheets that are wavelength of one-to-one hundred in lengths and are bound at both of their ends by buckyballs. They are renowned for being hollowed and cage-like and are available in a number of graphite cylinder forms. Their surface characteristics, size, and other essential physical characteristics make them appropriate for drug encapsulating. These tiny tubes go within cells through endocytosis or insertion through the cell membrane. The microscopic structures of fullers were able to display mitochondrial targeting within cells as well as tissue targeting.[49]

Nano emulsions

The bioavailability of medications with limited water solubility can be improved using nano emulsions and self-emulsified systems for drug delivery, which have attracted significant curiosity in recent years. Non-homogeneous systems called nano emulsions are made up of two immiscible liquids, where one disperses as drops in the other. Oil-in-water nano emulsions are created when the SNEDDS, which are isotropic in mixtures of gasoline, surfactant being used co-surfactant, and drug, incorporate into water-based states while being lightly mixed. These methods increase the bioavailability in the oral cavity of medications with weak water solubility through a number of different mechanisms. In addition, Because the oil drops are so small, there is less surface friction between them and the water-based fluid of the GI tract, which promotes a more equal and thorough dispersion of medications throughout the GI tract.[50]

Dendrimers

Dendrimers are branched, tree-like macromolecules with a well-defined structure. They can carry drug molecules either on their surface or within their interior voids. Dendrimers offer a high drug-loading capacity and controlled-release properties. Methods for synthesizing dendrimers based on the dendrimer type and drug conjugation technique desired. Dendrimers can be created using one of two methods: Either the divergent route, where the dendrimer forms from the center and then extends outward, or the convergent route, where the development of the dendrimer begins from the outside. Dendrimers fundamentally take two separate routes to deliver the drug,

a) By the covalent attachment of a drug the dendrimer is degraded *in vivo* on the foundation of the presence of adequate enzymatic or an environment of favorable conditions that might cleave the bonds.
b) A drug's release as a result of alterations in the physical atmosphere, such as the temperature or pH.[51]

CONCLUSION

Nanotechnology has completely transformed the field of drug delivery systems, offering remarkable improvements in targe therapy, controlled release, and enhanced bioavailability of pharmaceutical agents. Acrossthe implementation of nanoscale carriers, Liposomes, nanoparticles made of polymers, microorganisms, and dendrimers are just a few examples, the drawbacks of traditional drug delivery methods have been effectively addressed. The nanotechnology-based drug delivery system has also shown promise in overcoming various chemological barriers, which previously limited the treatment of certain neurological disorders.

By encapsulating drugs within nanoparticles that can traverse these barriers, nanotechnology has expanded the therapeutic options for conditions that were once difficult to manage. In conclusion, the implementation of nanotechnology in DDS has unlocked vast potential in the field of medicine. By offering targeted and controlled drug release, enhanced bioavailability, and improved treatment efficacy, nanotechnology has revolutionized the way we deliver drugs to patients. As research continues to advance and technology becomes more refined, nanotechnology holds the promise of even more groundbreaking developments in drug delivery, leading to better treatments and ultimately, improved patient outcomes. However, further research, collaboration, and regulatory efforts are required to ensure the safe and widespread adoption of nanotechnology in pharmaceutical applications.

REFERENCES

1. Telange DR, Patil AT, Pethe AM, Fegade H, Anand S, Dave VS. Formulation and characterization of an apigenin-phospholipid phytosome (APLC) for improved solubility, *in vivo* bioavailability, and antioxidant potential. Eur J Pharm Sci 2017;108:36-49.
2. Bhatia S, Bhatia S. Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. In: Natural Polymer Drug Delivery Systems: Nanoparticles, Plants, and Algae. Germany: Springer; 2016. p. 33-93.

3. Cojocaru FD, Botezat D, Gardikiotis I, Uritu CM, Dodi G, Trandafir L, *et al*. Nanomaterials designed for antiviral drug delivery transport across biological barriers. Pharmaceutics 2020;12:171.
4. Kipp JE. The role of solid nanoparticle technology in the parenteral delivery of poorly water-soluble drugs. Int J Pharm 2004;84:109-22.
5. Patil AS, Pethe AM. Quality by design (QbD): A new concept for development of quality pharmaceuticals. Int J Pharm Qual Assur 2013;4:13-9.
6. Liosis C, Papadopoulou A, Karvelas E, Karakasidis TE, Sarris IE. Heavy metal adsorption using magnetic nanoparticles for water purification: A critical review. Materials 2021;14:7500.
7. Biju S, Talegaonkar S, Mishra P, Khar R. Vesicular systems: An overview. Indian J Pharm Sci 2006;1:68.
8. Telrandhe UB, Galat LG, Chavan SD, Kamble MA, Gunde MC, Khirsagar RV. Formulation and evaluation of antimicrobial ointment from *Acacia auriculiformis* leaves extract. Int J Drug Deliv Technol 2023;13:665-9.
9. Farah FH, Farah FH. Nanocarriers as delivery systems for therapeutics agents. Int J Pharm Sci Res 2019;10:3487-507.
10. Malik S, Muhammad K, Waheed Y. Emerging applications of nanotechnology in healthcare and medicine. Molecules 2023;28(18):6624.
11. Sakamoto JH, Van de Ven AL, Godin B, Blanco E, Serda RE, Grattoni A, *et al*. Enabling individualized therapy through nanotechnology. Pharmacol Res 2010;62:57-89.
12. Prasad M, Lambe UP, Brar B, Shah I, Manimegalai J, Ranjan K, *et al*. Nanotherapeutics: An insight into healthcare and multi-dimensional applications in medical sector of the modern world. Biomed Pharmacother 2018;97:1521-37.
13. Filipczak N, Pan J, Yalamarty SS, Torchilin VP. Recent advancements in liposome technology. Adv Drug Deliv Rev 2020;156:4-22.
14. Tiwari G, Tiwari R, Sriwastawa B, Bhati L, Pandey S, Pandey P, *et al*. Drug delivery systems: An updated review. Int J Pharm Investig 2012;2:2.
15. Manzari MT, Shamay Y, Kiguchi H, Rosen N, Scaltriti M, Heller DA. Targeted drug delivery strategies for precision medicines. Nat Rev Mater 2021;6:351-70.
16. Mandal B, Bhattacharjee H, Mittal N, Sah H, Balabathula P, Thoma LA, *et al*. Core-shell-type lipid-polymer hybrid nanoparticles as a drug delivery platform. Nanomedicine 2012;9:474-491.
17. Wang Y, Kohane DS. External triggering and triggered targeting strategies for drug delivery. Nat Rev Mater 2017;2:17020.
18. Raj S, Khurana S, Choudhari R, Kesari KK, Kamal MA, Garg N, *et al*. Specific targeting cancer cells with nanoparticles and drug delivery in cancer therapy. Semin Cancer Biol 2021;69:166-77.
19. Kalyane D, Raval N, Maheshwari R, Tambe V, Kalia K, Tekade RK. Employment of enhanced permeability and retention effect (EPR): Nanoparticle-based precision tools for targeting of therapeutic and diagnostic agent in cancer. Mater Sci Eng 2019;98:1252-76.
20. Agrawal S, Budhwani D, Gurjar P, Telange D, Lambole V. Pullulan based derivatives: Synthesis, enhanced physicochemical properties, and applications. Drug Deliv 2022;29:3328-39.
21. Bekmurzayeva A, Duncanson WJ, Azevedo HS, Kanayeva D. Surface modification of stainless steel for biomedical applications: Revisiting a century-old material. Mater Sci Eng 2018;1:1073-89.
22. Khan W, Muntimadugu E, Jaffe M, Domb AJ. Implantable Medical Devices. Focal Controlled Drug Delivery. Germany: Springer Science and Business Media; 2024. p. 33-59.
23. Wijmans JG, Baker RW. The solution-diffusion model: A review. J Membr Sci 1995;15:1-21.
24. Radulescu M, Popescu S, Ficai D, Sonmez M, Oprea O, Spoiala A, *et al*. Advances in drug delivery systems, from 0 to 3d superstructures. Curr Drug Targets 2018;19:393-405.
25. Patra JK, Das G, Fraceto LF, Campos EV, Rodriguez-Torres MD, Acosta-Torres LS, *et al*. Nano based drug delivery systems: Recent developments and future prospects. J Nanobiotechnol 2018;16:1-33.
26. Mohammadi K, Sani MA, Azizi-Lalabadi M, McClements DJ. Recent progress in the application of plant-based colloidal drug delivery systems in the pharmaceutical sciences. Adv Colloid Interface Sci 2022;102734.
27. Jafari SM, McClements DJ. Nanotechnology approaches for increasing nutrient bioavailability. Adv Food Nutr Res 2017;81:1-30.
28. George A, Shah PA, Shrivastav PS. Natural biodegradable polymers based nano-formulations for drug delivery: A review. Int J Pharm 2019;561:244-64.
29. Cimino C, Maurel OM, Musumeci T, Bonaccorso A, Drago F, Souto EM, *et al*. Essential oils: Pharmaceutical applications and encapsulation strategies into lipid-based delivery systems. Pharmaceutics 2021;13:327.
30. Anarjan FS. Active targeting drug delivery nanocarriers: Ligands. Nano Struct Nano Objects 2019;19:100370.
31. Kesharwani P, Bisht A, Alexander A, Dave V, Sharma S. Biomedical applications of hydrogels in drug delivery system: An update. J Drug Deliv Sci Technol 2021;66:102914.
32. Bassendine MF, Taylor-Robinson SD, Fertleman M, Khan M, Neely D. Is Alzheimer's disease a liver disease of the brain. J Alzheimers Dis 2020;75:1-14.
33. Goonoo N, Bhaw-Luximon A, Ujoodha R, Jhugroo A, Hulse GK, Jhurry D. Naltrexone: A review of existing sustained drug delivery systems and emerging nano-based systems. J Control Release 2024;183:154-66.
34. Keiper A. The nanotechnology revolution. New Atlantis 2003;2:17-34.
35. Roco MC. The long view of nanotechnology development: The National Nanotechnology Initiative at 10 years. J Nanopart Res 2011;13:427-45.

36. Payal, Pandey P. Role of nanotechnology in electronics: A review of recent developments and patents. Recent Pat Nanotechnol 2022;16:45-66.
37. Patil SS, Shedbalkar UU, Truskewycz A, Chopade BA, Ball AS. Nanoparticles for environmental clean-up: A review of potential risks and emerging solutions. Environ Technol Innov 2016;5:10-21.
38. Joshi M. The impact of nanotechnology on polyesters, polyamides and other textiles: In Polyesters and Polyamides. New Delhi: Woodhead Publishing; 2008. p. 354-415.
39. Ferdous Z, Nemmar A. Health impact of silver nanoparticles: A review of the biodistribution and toxicity following various routes of exposure. Int J Mol Sci 2020;21:2375.
40. Buzea C, Pacheco II, Robbie K. Nanomaterials and nanoparticles: Sources and toxicity. Biointerphases 2007;2:MR17-71.
41. Pokrajac L, Abbas A, Chrzanowski W, Dias GM, Eggleton BJ, Maguire S, *et al*. Nanotechnology for a sustainable future: Addressing global challenges with the international network4sustainable nanotechnology. ACS Nano 2021;15:18593-20694.
42. Upadhyay A, Mukhuty S, Kumar V, Kazancoglu Y. Blockchain technology and the circular economy: Implications for sustainability and social responsibility. J Cleaner Product 2021;293:26130.
43. Vashist SK, Schneider EM, Luong JH. Commercial smartphone-based devices and smart applications for personalized healthcare monitoring and management. Diagnostics (Basel) 2014;4:104-28.
44. Kumar A, Gupta K, Dixit S, Mishra K, Srivastava S. A review on positive and negative impacts of nanotechnology in agriculture. Int J Environ Sci Technol 2019;16:2175-84.
45. Hossain A, Skalicky M, Brestic M, Mahari S, Kerry RG, Maitra S, *et al*. Application of nanomaterials to ensure quality and nutritional safety of food. J Nanomater 2021;9336082:1-19.
46. Groso A, Petri-Fink A, Magrez A, Riediker M, Meyer T. Management of nanomaterials safety in research environment. Part Fibre Toxicol 2010;7:40.
47. Molahalli V, Shetty A, Sharma A, Bijapur K, Soman G, Hegde G. Risks and ethics of nanotechnology: An overview. In: Nanoparticles and Plant-Microbe Interactions. Netherlands: Elsevier Science; 2023. p. 35-68.
48. Patra CR, Bhattacharya R, Mukhopadhyay D, Mukherjee P. Fabrication of gold nanoparticles for targeted therapy in pancreatic cancer. Adv Drug Deliv Rev 2010;62:346-61.
49. Shete VS. Microspheres as a unique drug carrier for controlled drug delivery: A review. Asian J Pharm 2023;15:17.
50. Sosnik A, Augustine R. Challenges in oral drug delivery of antiretrovirals and the innovative strategies to overcome them. Adv Drug Deliv Rev 2016;103:105-20.
51. Satija J, Gupta U, Jain NK. Pharmaceutical and biomedical potential of surface engineered dendrimers. In: Critical Reviews™ in Therapeutic Drug Carrier Systems. United States: Begell House; 2007. p. 24.

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