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A REVIEW ON---NANOTECHNOLOGY IN PHARMACEUTICALS

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ABSTRACT

Nanotechnology has revolutionized various fields, including pharmaceuticals, by offering novel solutions for drug delivery, imaging, and diagnostics. One of the most important unit operations in the pharmacy sector is size reduction. This leads to enhanced product formulation opportunities, reduced toxicity, more stability and bioavailability, and better release. Nanotechnology is currently becoming more and more popular due to its potency. Complex nanoparticles can now be created for a wide range of biomedical applications thanks to developments in nanotechnology.

Using designed nanoparticles that interact to treat diseases in biological contexts is becoming more realistic due to the rapid growth of nanotechnology. Drug distribution, subsequent release, and kinetics are all altered by nanoparticles. Targeting a particular tissue or cell is one of the consequences; unwanted side effects are avoided by a controlled release.

The advancement of nanomedicine, tissue engineering, nanorobots, biosensors, biomarkers, and other applications are examples of how nanotechnology is currently used in the Pharmaceutical Industry. The field of pharmaceutical nanotechnology offers prospects in areas where current, more traditional technologies may be nearing their limits, enhance materials, and medical devices, and assist in the development of new technology. Thus, improvements in this discipline will lead to better drug delivery in the coming years, along with other

opportunities in pharmacy and medicine. Nanotechnology has advanced recently, allowing for the creation of complex nanoparticles for various biological uses. The prospect of using tailored materials has expanded due to the rapid development of nanotechnology. Interacting nanoparticles in biological environments to treat diseases.

Keywords: Pharmaceutical Nanotechnology, Pharmaceuticals, Nanoparticles, Nanosystems, Nanomaterials

INTRODUCTION

Integrating nanotechnology with pharmaceuticals has led to significant improvements in drug delivery, bioavailability, and therapeutic efficacy. Nanotechnology has emerged as a promising avenue in pharmaceutical research, offering unprecedented opportunities to enhance drug delivery, improve therapeutic efficacy, and develop personalized treatment strategies. The Latin term "nano" means "dwarf" **[1]**.

Nanotechnology is the science of manipulating atoms and molecules in structures that vary from 1 to 100 nm in size. By using nanoscale materials, they can exhibit dramatically new properties. Nanotechnology has the potential to be used in a wide range of pharmaceutical applications, which include in vitro diagnostics, drug discovery, and drug delivery. Researchers from the University of Tokyo named Norio Taniguchi coined the word "nanotechnology" in 1974 to describe the capacity to manufacture materials at the nanoscale **[2]**. Nanotechnology is the study of multidisciplinary field events that occur at the molecular level and on the nano-length scale **[3]**.

Nanoparticles are characterized as particulate dispersions or solid particles with diameters ranging from 10-1000 nm. The medication has been dissolved, trapped, encapsulated, or linked to a nanoparticle matrix. Depending on the method of preparation, nanoparticles, nanospheres, or nanocapsules can be obtained.

Nanocapsules are structures that limit the drug to a compartment bordered by a separate polymer membrane, whereas nanospheres are matrix systems in which the medication is spread uniformly and evenly. Nanometre-sized drugs improve performance in several dose formats.

Benefits of Nanoparticles:

The following are the primary benefits of nano sizing:

1. Increased Surface Area, rate of dissolution
2. Improved Solubility
3. A higher Oral Bioavailability,
4. Faster Onset of Therapeutic Action,
5. Less Dose is Required,

6. Reduction in Fed/Fasted Variability, Patient-to-Patient Variability **[4]**.

Limitations of Nanoparticles:

1. Cytotoxicity.
2. Alveolar inflammation.
3. Inflammation of the lungs and the risk of lung cancer.
4. If too much polyvinyl alcohol is used as a stabilizer, toxicity problems can arise.
5. Manufacturing costsare high.
6. Difficult to handle the physical form due to particle-particle aggregation.

Various types of Nanotechnologies:

1) **Nano devices**: These are utilized to deliver medicinal and diagnostic substances.It falls under three groups of powerful molecular technologies:

• Nanoscale instruments and materials for biosensors, smart medications, controlled drug delivery, and enhanced diagnostics.

• Molecular devices and medical nanorobots aid in the quick identification and management of microorganisms as well as the advancement of physiological function.

• Genomic and proteomic medicine with artificial microbial robots.

2) **Nano Pharmaceuticals**: These drugs are used to treat lung conditions, diabetes, cancer, atherosclerosis, tissue cell repair, gene therapy, antiviral drugs, and tissue engineering **[5]**.

SYSTEMS BASED ON PHARMACEUTICAL NANOTECHNOLOGY

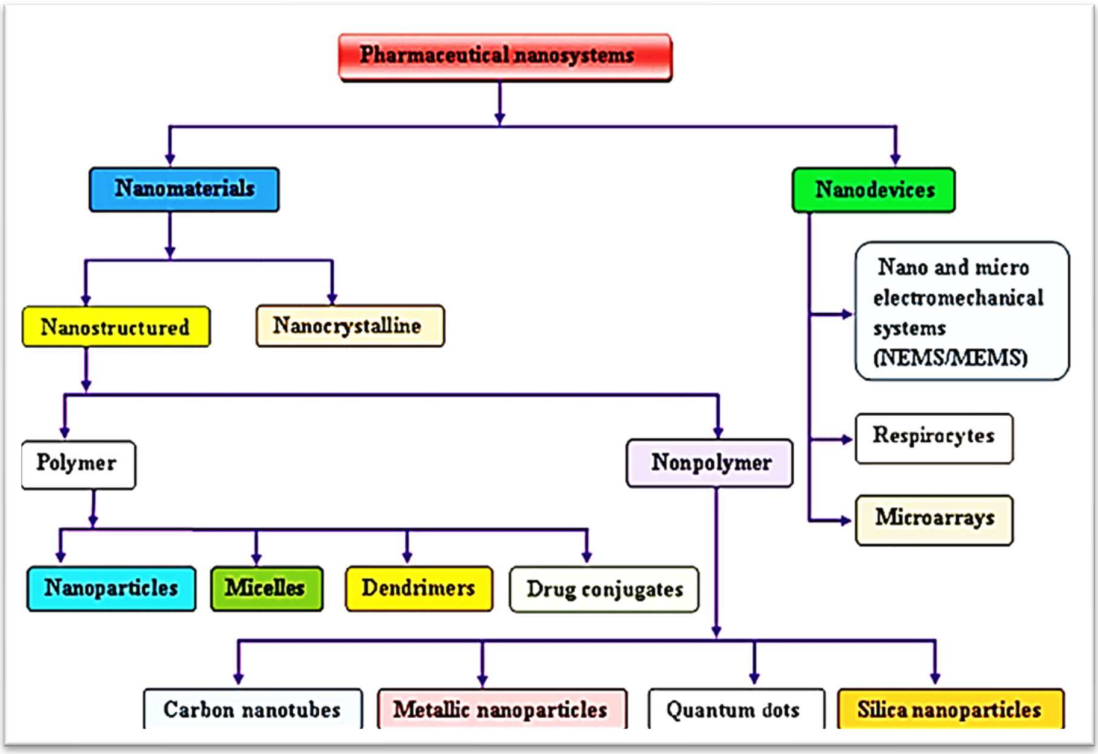


Figure 1: Various types of Pharmaceutical Nanosystems [2]

The two primary categories of nanotools that pharmaceutical nanotechnology offers are nanomaterials and nanodevices, which play a major role in the area of linked fields and pharmaceutical nanotechnology.

Biomaterials known as nanomaterials are utilized, for instance, as scaffolding for tissue-engineered products or in dental or orthopedic implants. These substances can be further divided into nanostructured and nanocrystalline substances.

Nanomaterials in Drug Delivery: Nanoparticles, liposomes, dendrimers, and nanofibers represent key nanomaterials employed in drug delivery systems. These nanostructures enable the encapsulation, protection, and controlled release of therapeutic agents, thereby overcoming limitations associated with conventional drug formulations. Moreover, surface modification techniques facilitate targeted drug delivery to specific tissues or cells, enhancing therapeutic outcomes while minimizing adverse effects.

Nanocrystalline materials are easily made and can be used to replace less efficient bulk materials. Raw nanomaterials can be employed in medication encapsulation and bone regeneration prostheses, implants,and all types ofbone replacements.

Nanostructured materials, such as quantum dots, dendrimers, fullerenes, and carbon nanotubes, are processed forms of raw nanomaterials that provide particular morphologies or functionality. Nanodevices are nanoscale miniature devices, such as nano- and microelectromechanical systems (NEMS/ MEMS), microfluidics (control and manipulation of micro or nanolitre fluids), and microarrays (such as DNA, protein, cell, and antibody are the various types of biological assays). Biosensors and detectors that identify minute amounts of bacteria, airborne pathogens, biological dangers, and illness indicators are a few examples, as are certain intelligent devices like respirocytes **[3]**.

TYPES OF PHARMACEUTICAL NANOSYSTEMS:

1. Nanoparticles

In nanotechnology, nanoparticles are the basic building blocks. Metallic, metal oxide, organic, and carbon-based nanoparticles range in size from 1 to 100 nm. In addition to their composition, nanoparticles come in a variety of sizes, shapes, and dimensions **[6]**.

In a nanoparticle matrix, the medication is dissolved, encapsulated, entrapped, or connected. By the preparation technique, one can obtain nanoparticles, nanospheres, or nanocapsules. Controlling the size of the particles, their surface characteristics, and the release of pharmacologically active compounds are the main objectives when designing nanoparticles as a delivery

system. This allows the medicine to act at the right spot at the right dose and rate **[3]**.

2. Polymeric Micelles

A nanoparticle having a hydrophilic outside and a hydrophobic inside is known as a polymer micelle. Micelles composed of hydrophobic materials and polyion complexes can be classified into two primary groups. In the past, hydrophobic and hydrophilic building blocks were commonly found in amphiphilic copolymers. The spontaneous synthesis of nanoparticles in an aqueous phase results from a balance between these two essential elements. Poly (ethylene glycol, or PEG) is employed as a hydrophilic block in the majority of block copolymers **[7]**.

Liquids consist of individual molecules gathered into groupings called micelles. They have a hydrophilic group-covered hydrophobic core that is protected from water.

For example, the medication paclitaxel is used to provide chemotherapy to cancer patients and is combined with polymeric micelles **[8]**.

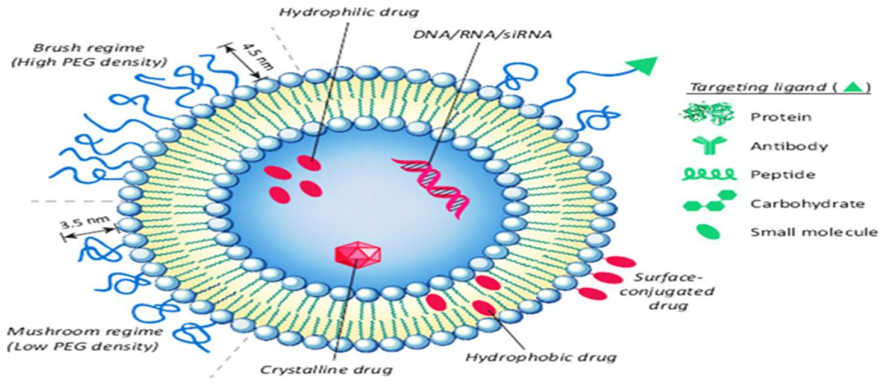


Figure 2: The structure of Liposomes

3. Liposomes

A lipid bilayer encircling the aqueous core of a liposome functions as a membrane-like barrier, isolating the inner liposome from the bulk outside. They were initially identified as enlarged phospholipid systems by Bangham and his associates in 1961. The terms "lipos," which means fat, and "soma," which means body, were combined to create the word liposomes.

Amphiphilic molecules are lipids, that have one component that loves water (hydrophilic) and the other that hates (hydrophobic) it. The lipids when coming into contact with water due to the hydrophobic regions of the molecule's unfavourable interactions with the solvent. Liposomes are made up of an inner water core and a lipid bilayer that acts as a membrane to surround the aqueous center **[9]**.

Lipid-based drug delivery systems can deliver drugs to targeted tissues/cells in a controlled and site-specific manner, making them a promising option for pharmaceutical/biomedical researchers and industries **[10]**. The ability of liposomal formulations to incorporate high-quality drugs into the liposome's interior through the use of the ammonium sulfate gradient method and the ability to insert pegylated lipids into the liposomes to avoid their accumulation in the tumor site are two of the main advantages that make them clinically suitable carriers**.**

4. Dendrimers

A novel class of nanoscale, three-dimensional, core-shell structures known as dendrimers can be manufactured for a variety of uses. The chemical and physical characteristics of the dendrimers can be precisely controlled thanks to specialized chemistry procedures. The methods can also be applied to creating innovative pharmaceuticals with unique activities, but they are particularly helpful in the delivery of drugs. Polyvalent dendrimers interact with several pharmacological targets at once.

They have the potential to become innovative, focused cancer treatments. Using cDNA oligonucleotides, dendrimers can be attached to various biofunctional moieties, such as folic acid, to create clustered molecules that target cancer cells by overexpressing the high-affinity folate receptor **[11]**.

Dendrimers are a superior drug delivery system than conventional nanomaterials and polymers because of their globular architecture, well-defined number of surface functionalities, monodispersity, strong cellular uptake ability, consisting of synergistic or multivalence effect, controllable size, and high efficiency in gene and drug delivery **[12, 13]**.

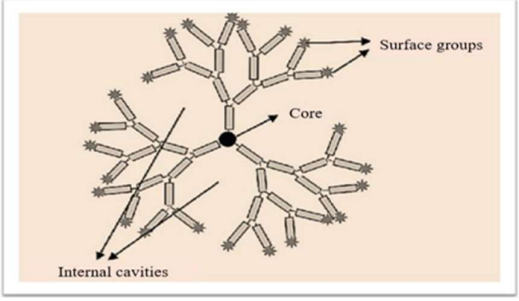


Figure 3: Structure of Dendrimers

5. Polymer Drug Conjugates

Polymers like polyethylene glycol (PEG) and PEG-camptothecin are conjugated with protein and peptide medicines.Additionally, it can prolong the half-life of medications in plasma by preventing the breakdown of protein medicines in the stomach and by making them soluble in water. Because of

their conjugated polymers, white blood cells are unable to identify them as foreign particles.More recently, brush polymer-drug conjugates were created using ring-opening metathesis copolymerization, and they dissolved in water more readily than polymer-drug conjugates **[8]**.

Table 1: Several drugs and treatments that use polymer-drug conjugates

Drug	Treatment
L-asparaginase	Acute lymphoblastic leukemia
Adenosine deaminase	Adenosine deaminase enzyme deficiency
PEGylated IFN-á-2a	Hepatitis C

7. Carbon Nanotubes

Carbon nanotubes (CNTs) and fullerenes are the two primary constituents of carbon-based nanoparticles. All carbon nanotubes (CNTs) are rolled graphene sheets. Because these materials are 100 times stronger than steel, they are mostly utilized for structural reinforcement. Single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) are two types of carbon nanotubes. Because they are non-conductive across the tube and thermally conductive along their length, carbon nanotubes are special in this regard.

Single-walled carbon nanotubes have been employed as a platform for research into surface-protein and protein-protein binding **[15]**.

Allotropes of carbon with a hollow cage structure made up of sixty or more carbon atoms are called fullerenes. C-60's structure, known as Buckminsterfullerene, resembles a hollow football. These structures' carbon units are arranged in pentagonal and hexagonal patterns.

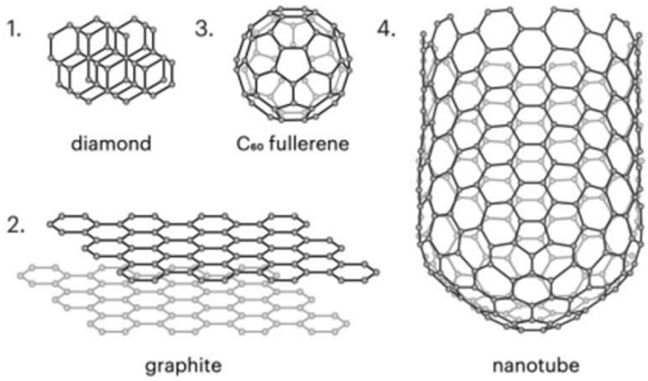


Figure 4: The structure of the carbon nano tube

Table 2: Types of Nanotubes

MWNTs multi walled nanotubes; f-CNTs functionalized carbon nanotubes; SWNTs-PL-PEG-NH_2 amine-functionalized single-walled carbon nanotubes

Type of nanotubes	Drug	Method of immobilization
MWCNTs	Cisplatin	Encapsulation *via* capillary forces
f-CNTs	Amphotericin B	Conjugated to carbon nanotubes
SWCNTs	Gemcitabine	Encapsulation
MWNTs	Epirubicin hydrochloride	Adsorption
MWCNTs@poly(ethylene glycol-*b*-propylene sulfide)	Doxorubicin	Adsorption
f-CNTs	Sulfamethoxazole	Adsorption
SWNTs-PL-PEG-NH_2	Pt(IV) prodrug-FA	Covalent amide linkages
SWNTs	Cisplatin – EGF	Attachment to carbon nanotubes *via* amide linkages
MWCNTs	Dexamethasone	Encapsulation

7. Metallic Nanoparticles

Dependent on the size, optical, magnetic, and electrical characteristics. MNPSis produced using chemical, physical, and environmentally friendly methods laserablation and condensation evaporation are examples of physical approaches. It offers even dispersion and reduced solvent contamination. Reducing agents such as ascorbate, sodium borohydride, and tollensreagent are used in the chemical procedure. Plant species, fungi, and bacteria are used in the biological approach to produce metallic nanoparticles **[14]**. For a variety of therapeutic compounds, silicon nanoparticles are thought to be an acceptable nanocarrier. Mesoporous silica nanoparticles (MSNs) with enormous surface areas and controlled size and shape pores enhance cellular internalization, prevent unstable drugs from degrading, and allow for high trapping of either hydrophobic or hydrophilic drugs **[15]**, i.e. the majority of metallic nanoparticles utilized in drug delivery systems are iron (II, III) oxide (Fe_2O_3, Fe_3O_4, FeO), zinc oxide (ZnO), gadolinium (Gd), silica, and gold (Au), nickel (Ni), silver (Ag), platinum (Pt), and (TiO2), as well as particles of titanium dioxide (SiO_2) **[16]**.

8. Quantum Dots

Quantum dots (QDs) are nanocrystals, 2–10 nm in size, Under UV light stimulation, quantum dots are microscopic crystals that illuminate. An array of diverse colors and light intensities can be produced in samples that function as spectral bar codes by mixing different amounts ofdots within a single bead. DNA sequences can be engineered to attach to particular DNA sequences using latex beads packed with crystal. The colors that the crystals release become active when light strikes them, illuminating the interesting sequences **[17]**.

These are semiconducting materials consisting of an organic shell coated in an inorganic core. When triggered, qds can release fluorescence.Luminous. Qds are a

valuable technique for tracking and visualizing intracellular activities because of this special quality. Tumor imaging and non-invasive diagnosis are made possible by the accumulation of qds in tumor tissue. When investigated in vitro, qds have demonstrated encouraging outcomes for targeted chemotherapy, imaging-guided therapy, and quick localizations of HER-2 receptors **[18]**.

9. **Silica Nanoparticles**

Mesoporous silica nanoparticles and xerogels offer greater porousness, convenient functionalization, and enhanced biocompatibility.grid. Xerogels are drug-loaded using the sol-gel method and have a very porous surface area. Changes in synthesis circumstances, such as temperature, pressure, and reagent ratio, can regulate the rate at which drugs are released. Medication containing xerogels includes phenytoin, cisplatin, nifedipine, doxorubicin, metronidazole, and heparin.

Mesoporous silica nanoparticles are homogeneous in structure and have a large surface area for drug absorption. Mesoporous delivery systems are used to deliver anticancer, antibacterial, and heart disease medications, with drug release regulated by diffusion **[19]**.

APPLICATIONS OF NANO-TECHNOLOGY IN THE PHARMACEUTICAL FIELD

1. Pharmaceutical aerosols using Nanotechnology:

Pharmaceutical aerosols utilizing nanotechnology offer promising advances in drug delivery. Certain medications are not good candidates for creating aerosols; however, by using the principles of nanotechnology to create nanosuspensions for medications that are insoluble in both aqueous and oily media, enhanced Aerosol-administered medications now have better bioavailability thanks to pharmacokinetics. Furthermore, the generation of bioadhesive nanoparticles contributed to extending the medication's mucosal residence time, which in turn enhanced drug absorption and, ultimately, bioavailability **[20]**.

Examples of pharmaceutical aerosols aresalbutamol/salmeterol; metered dose inhalers that deliver powder dosage form into the lungs; and dry powder inhalers that relax the muscles in the largeairways.

2.Transdermal medication delivery:

Transdermal medication delivery employing nanotechnology holds significant potential for enhancing drug absorption through the skin. Nanosized carriers like liposomes,nanoparticles,and micelles can encapsulate drugs improving their bioavailability and penetration.

The lowest particle sizes are found in SLN dispersions with a low lipid content (up to 5%). Poor viscosity and a larger concentration of dispersed lipids are also detrimental to cutaneous delivery. In the majority of cases, it's crucial to incorporate

the SLN dispersion into an ointment or gel to create a consistency that can be applied topically. The integration stage denotes a further decrease in the lipid content. The formation of semi-solid, gel-like systems from an increase in the solid lipid content of SLN dispersion may make them appropriate for direct skin application **[21]**.

3.**Drug delivery**

Utilizing nanotechnology in drug delivery entails creating nano-sized carriers that carry medications to precise bodily locations, increasing therapeutic efficacy and reducing unwanted effects. Because of their small size and special characteristics, nanoparticles, liposomes, dendrimers, and micelles are frequently used as carriers. These carriers can enhance solubility, prevent drug degradation, allow for regulated release, and make it easier to distribute medications to particular tissues or cells. Systems for delivering drugs based on nanotechnology have enormous potential to treat a wide range of illnesses.

Nanoparticles increase the solubility of medications that are not very soluble in water. By lowering immunogenicity, increasing drug half-life, decreasing drug metabolism, enabling controlled release of therapeutic chemicals, improving drug bioavailability, and increasing specificity, nanoparticles alter the pharmacokinetics of pharmaceuticals **[22]**.

4. Tuberculosis management

Chemotherapy or vaccinations are the two main methods of controlling tuberculosis. A common method for enhancing the pharmacokinetic profile of anti-TB medications and delivering them for long-term therapy is using liposomes and lipid nanoparticles.

Adequate and consistent medication delivery to the cells is essential for the treatment of tuberculosis. To give TB cells medication in a sustainable manner, the NP was linked to medications like rifampin (RMP), isoniazid (INH)/Pyrazinamide (PZA), and coated with PEG **[14]**. Because of their high drug-loading capacity, biodegradability, and biocompatibility, inhalable nanoparticles have been shown to promote mucosal cell adhesion and drug administration to the respiratory system in the treatment of tuberculosis (TB).

5**. Gene therapy**

Liposomes used in gene therapy are 100 nm wide. It is employed to introduce genetic material into cells. Due to the quick uptake of galactose and polyethylene glycol by liver Kupffer cells, liposomes containing these molecules efficiently target liver cells. Liposomal nanoparticle-based gene therapy has been tested for Wilson's disease, hereditary hemochromatosis, and several liver ailments. Additionally, polymeric nanoparticles used for gene therapy against breast cancer cells have shown an antiproliferative effect.

Due to their structural flexibility, hyperbranched topology, and cationic nature—which permits DNA binding at physiological pH—dendrimers have gained a lot of interest among other gene-delivery nanomaterials **[23]**.

6. Pulmonary Drug Delivery

Drug delivery by pulmonary nanoparticlesOne very intriguing application of SLN is usually its pulmonary administration. SLN powders shouldn't be given to the lungs since the particles are too fine and will be exhaled. The dispersal of particles of aqueous SLN dispersions is an extremely basic method. The important thing to remember is that the SLN shouldn't build up during aerosolization. An aerosol collision with the glass wall of the beaker resulted in the collection of aerosol droplets. In essence, this demonstrates that SLN is ideal for pulmonary administration. Once the chemical has been localized in the alveoli and bronchial tube, it can be released from the lipid particles in a regulated manner **[14]**.

7. Tissue Engineering

Tissue engineering coupled with nanotechnology offers innovative approaches for regenerative medicine and the development of functional tissue substitutes.

Nanotechnology may be able to aid in the repair or regeneration of tissue. "Tissue engineering" uses scaffolding composed of the appropriate nanomaterials and growth hormones to artificially enhance the expansion of cells. Organ transplants and implanted devices are examples of modern conventional treatments that tissue engineering has the potential to replace. Biomaterials that can control and preserve cell behaviour can be used with nano- and microtechnology to create scaffolds for tissue engineering **[24]**.

8. Central nervous system diseases

Nanotechnology has great potential in the treatment of neurological disorders mainly Alzheimer’s disease, brain tumors, stroke, and Parkinson’s disease.

Nanotechnology can insist that small molecules and medicines cross the BBB.The NPcan pass the blood-brain barrier (BBB), and it can be utilized to treat a variety of conditions including aging, infectious infections, lysosomal storage disease, brain tumors, and Alzheimer's disease. Most Drugs or molecules with low molecular mass and high lipid solubility are the only substances that can pass through the BBB, preventing therapeutic particles from doing so. NP can directly transfer medications via BBB and has a high affinity. Drug kinetics and efficiency will be enhanced across the tissue spectrum by a variety of transport molecules, including growth factors, insulin, and transferrin **[4]**.

9. Bone diseases

Nanotechnology has been used for various bone diseases,including osteoporosis, bone cancer, and osteoarthritis.Nanoparticles can deliver therapeutic agents such as anti-resorptive drugs/growth factors directly to the site of bone disease.

Without causing any harm to bone structures, the calcium-phosphate-based NP is utilized to deliver drugs to treat bone disorders. For joint inflammation,Bisphosphonates are among the medications used to treat metabolic bone cancer, osteoarthritis, and osteosarcoma.The NP progress in bone regeneration using silica and magnetic nanoparticles **[14]**.

Example-Incorporating metallic nanoparticles into scaffolds has been observed to enhance their mechanical strength, cellular adhesion, and bone-forming potential.

10. Asthma

Nanosized carriers such as nanoparticles or liposomes can improve the delivery of asthma. Nanotechnology can improve asthma treatment outcomes, patient compliance, and therapeutic protection compared to traditional drug administration methods. Topical use of asthma-related anti-inflammatory and bronchodilator medications, such as glucocorticoids and β2-agonists, is preferred over systemic usage. Since the importance of local medicine delivery for asthma is well established, nanotechnology has been employed to improve drug delivery. Inhalation also increases deeper lung permeability **[24]**.

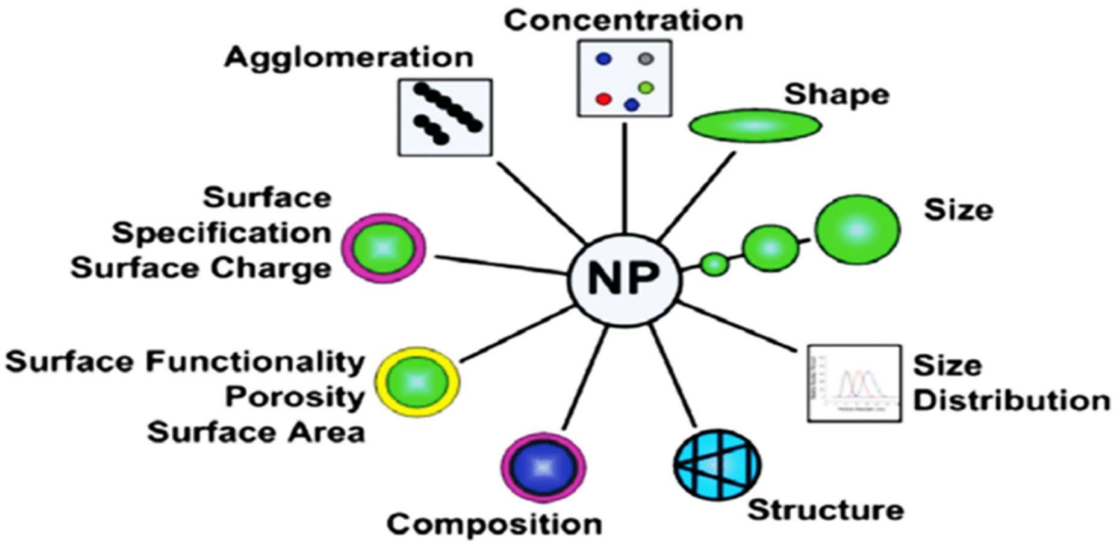
11. Nanotechnology in imaging and diagnostics:

Nanotechnology is vital in improving imaging modalities and diagnostic techniques for better disease detection and monitoring. This discusses using nanomaterials, such as quantum dots, gold nanoparticles, and magnetic nanoparticles, in imaging modalities such as MRI, CT scans, and fluorescence imaging.

Importance of Nanotechnology in Pharmaceuticals:

- Pharmaceutical nanotechnology helps combat multiple diseases by detecting disease-associated anti-gens and microbes and viruses that cause disease.
- Pharmaceutical nanotechnology has played a very important role in overcoming some drawbacks of conventional dosage forms such as tablets, capsules, etc.
- Nanoparticles have been proven to be useful as drug-delivery vehicles. Many uses for nanoparticulate drug delivery systems exist including gene therapy, cancer therapy, and AIDS.

KEY PARAMETERS FOR CHARACTERIZATION OF NANOPARTICLES



FUTURE PROSPECTS AND CHALLENGES OF PHARMACEUTICAL NANOTECHNOLOGY

Within the pharmaceuticals and medical fields, nanotechnology is regarded as a relatively new and quickly developing field When it comes to increased efficacy and less adverse medication reactions, nanoparticles provide several benefits as drug delivery vehicles. When it comes to changing several aspects of medical therapy, including diagnostics, disease monitoring, equipment operation, regenerative medicine, vaccine development, and medication administration, nanotechnology holds a lot of promise for atomic manipulation. Finally, the application of nanotechnology will advance with our increasing knowledge of diseases at molecule state. Understanding the molecular signatures of disease in the future will lead to advances in nanomedicine applications.

Despite the promising prospects of nanotechnology in pharmaceuticals, several challenges and safety concerns must be addressed. These include concerns regarding toxicity, biocompatibility, immunogenicity, and regulatory hurdles associated with the development and commercialization of nanomedicines. Moreover, standardized protocols for characterization, manufacturing, and quality control are essential to ensure the safety and efficacy of nanotechnology-based pharmaceutical products.

CONCLUSION

Nanotechnology is a developing field that has the potential to transform drug delivery. Because of advancements in this field, certain nanomedicines on the market now have desired pharmacokinetic features,

lower toxicity, and increased patient compliance and clinical outcomes. The incorporation of nanoparticulate drug delivery technologies in preformulation work not only speeds up the development of new therapeutic moieties but also helps to reduce the attrition of new molecular entities due to unfavorable biopharmaceutical and pharmacokinetic features.

Pharmaceutical nanotechnology offers intelligent materials for tissue engineering and the delivery of bioactive and diagnostic materials both spatially and temporally. Prognostics, diagnostics, illness, and other fields were all greatly impacted by nanotechnology. Therapy of illnesses by providing chances, reach, and novel nanotechnology-based instruments.

Nanotechnology is a promising science with a variety of advantages and applications in the medical field. It overcame the problems associated with conventional drug delivery systems and took the chance to accomplishment in the production of COVID-19 vaccines based on lipid nanoparticles with higher efficiency over the other conventional vaccines. More efforts are needed to increase the number of FDA-approved nano-drugs and further studies must be done to understand the development of the unique properties of these magical particles.

Nanotechnology holds immense promise in revolutionizing the pharmaceutical industry by offering innovative solutions for drug delivery, imaging, and diagnostics. However, addressing the existing challenges and ensuring safety and efficacy is critical for the successful translation of nanomedicines from the laboratory to clinical practice.

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