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Nano Particles and Nano Fibers

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Abstract: Nanotechnology is an emerging technology with the potential to revolutionize the design, synthesis, and application of material at the nanometre level, which may range from 1 to 100 nanometres. When the material dimension reduces to the nano level, the physicochemical properties of the material get enhanced and produce unique optical and mechanical properties, which are not seen in the material at the macro level. Among the numerous nanomaterials synthesized, nanoparticles and nanofibers are found to be of great interest because of their substantial properties and applications.

Zero-dimensional nanostructures, commonly known as nanoparticles, are highly suitable for drug targeting, imaging, and diagnostics because of its size and high surface-to-volume ratio. They help in the controlled release of medicated formulation, increase the bioavailability of the drug, and inhibit systemic side effects. For instance, nanofibers, which are one-dimensional nanomaterials with a size in the nanometric region and longer in the micrometre region, find applications in tissue repair, biosensors, tissue engineering, wound dressing, superior tissue compatibility, high pore absorption, high flexibility, as well as applications in the field of biosensors.

The relevance of nanoparticles and nanofibers has applications in a wide spectrum of fields such as pharmaceuticals, biomedical engineering, environmental studies, and storage materials. Some of the most prominent applications of these nanoparticles are in the field of anticancer therapies, antimicrobial applications, regenerative medicine, biosensors, and smart fabrics. With rapid progress being made in their production as well as their characterization, the future of nanoparticles and nanofibers holds a promising future. The current research being carried out pertains to the development of multi-functional nanomaterials.

Keywords: Nanotechnology; Nanoparticles; Nanofibers; Drug delivery systems; Electrospinning; Controlled release; Biomedical applications; Tissue engineering; Surface modification; Nano-scale materials; Biocompatibility; Targeted therapy

1. INTRODUCTION

Nanotechnology is considered to be a branch of material and device scientific and engineering knowledge at the nanometre level, ranging from 1 to 100nm, where materials display distinct properties based on their sizes.

The history of nanotechnology started with a lecture titled "There's Plenty of Room at the Bottom" given by physicist Richard Feynman at an American Physical Society meeting in 1959. The word nanotechnology was coined in 1974 by Norio Taniguchi, while the 1980s saw advances in microscopy technology that made possible the research that could be done at the nanotechnology level.

The main disparity between bulk and nanomaterials is in terms of size-dependent properties. Bulk materials demonstrate intrinsic size-independent properties; however, nanomaterials possess unique properties that include increased surface area and reactivity; changes in optical and mechanical properties due to the quantum and surface effect. The relevance of nanotechnology cannot be overemphasized, especially with regard to pharmaceutical and biomedical applications, as well as industry. In pharmaceutical and biomedical contexts, it enhances pharmaceutical dosing, diagnosis, tissue reconstruction, and particular therapies. In industry, it advances material toughness, the efficiency of energy use, catalysis, electronics, and environment conservation.

2. PART A: NANO PARTICLES

2.1. Definition and characteristics

Nanoparticles refer to solid colloidal particles with sizes ranging from 1 to 100 nanometres, with some ranging up to 500 nm based on their intended use. This size puts matter at a nanoscale where physicochemical properties are different from matter at a macroscopic scale. Nanoparticles can consist of polymers, lipids, metal-based materials, and inorganic materials and have the capacity to encapsulate, adsorb, or chemically bind drugs.

The size of nanoparticles is one of the critical attributes of NPs; they are sufficiently small to easily pass biological barriers and live for a long time in the bloodstream. The high surface area-to-volume ratio of NPs improves biological membrane interaction and drug loading efficiency. The surface modification of NPs improves stability and biocompatibility.

Quantum effects are also an important area in the case of nanoparticles, especially metallic and semiconductor nanoparticles. When the size of the particle reduces to the nanoscale level, there are variations in the optical properties, electrical properties, and magnetic properties. These variations are utilized in imaging and diagnostic applications.

2.2. Types of Nanoparticles

2.2.1. Polymeric Nanoparticles

Polymeric nanoparticles are prepared using natural and synthetic polymers such as chitosan, PLGA, alginate, and gelatin. Polymeric nanoparticles have gained popularity due to their properties such as being biodegradable, non-toxic, and controlling drug release. The drugs can be incorporated either into the matrix or adsorbed onto the surface.

2.2.2. Metallic Nanoparticles

Metallic nanoparticles are gold nanoparticles, silver nanoparticles, iron oxide nanoparticles, and platinum nanoparticles. The optical properties of these nanoparticles are similar to the optical properties of metal nanoparticles. Silver nanoparticles are well-known for their antimicrobial properties. The anticancer properties of gold nanoparticles are well-known.

2.2.3. Lipid Nanoparticles

Lipid nanoparticles include solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs). They are made up of physiologic lipids and are proven to be safe. Lipid nanoparticles are effective in improving stability, bioavailability, and controlled release of drugs. They are used as vaccine and gene delivery carriers.

2.2.4. Nanoparticle Technology

Inorganic nanoparticles: These include silica nanoparticles, calcium phosphate nanoparticles, quantum dots, and ceramic nanoparticles. They have high stability and controlled surface chemistry. They can be used in imaging techniques, bone tissue regeneration, and for diagnostic purposes.

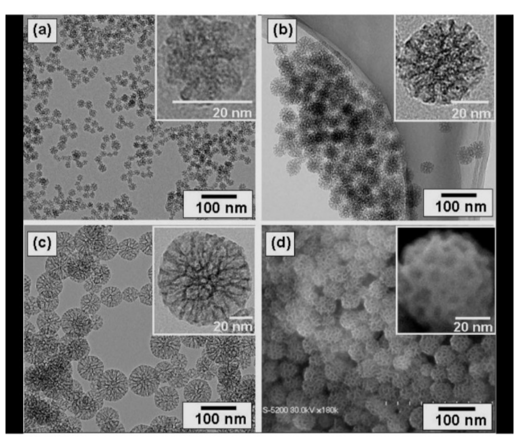


Fig1. *Nanoparticles*

3. METHODS OF PREPARATION

3.1. Nanoprecipitation

This method is straightforward and exploits the precipitation of nanoparticles from a polymer solution added to a non-solvent liquid. It is effective for the preparation of nanoparticles with a narrow size distribution and is a desirable method for heat-sensitive active substances.

3.2. Emulsification-solvent evaporation:

In this method, the pharmaceutical and polymer are dissolved in an organic solvent and emulsified in an aqueous solution. As the solvent evaporates, nanoparticles are formed. This method is mostly used for the preparation of polymeric nanoparticles.

3.3. Spray Drying

Spray-drying is carried out by atomizing a solution or a suspension into a hot drying chamber, resulting in a quick evaporation of the solvent, thus creating particles. Spray-drying is applicable at a large scale.

3.4. Green Synthesis

Green synthesis is a synthesis procedure involving the use of plant extracts or microorganisms or biological reducing agents to synthesize nanoparticles. The approach is non-toxic and friendly to the environment.

3.5. Ionic Gelation

It primarily applies to chitosan nanoparticles. Electrostatic attraction between opposite polymers and cross-linkers with mild conditions yield nanoparticles. It is also known as electrostatic solvent inversion.

3.6. Characterization Techniques

Particle size and Polydispersity Index (PDI) are determined by Dynamic Light Scattering (DLS). Size has been found to influence Drug release, stability, and biodistribution.

Zeta potential determines the surface charge and the colloid stability. A higher absolute zeta potential means increased stability.

Scanning electron microscopy (SEM) and Transmission electron microscopy (TEM) mainly provide qualitative details regarding the morphology of particles.

Fourier transform infrared spectroscopy is utilized to analyse the interaction between the drug substance and excipients.

The crystalline or amorphous form of nanoparticles is identified using the process of X-ray diffraction

Differential scanning calorimetry (DSC) evaluates heat and verifies encapsulation of the drug.

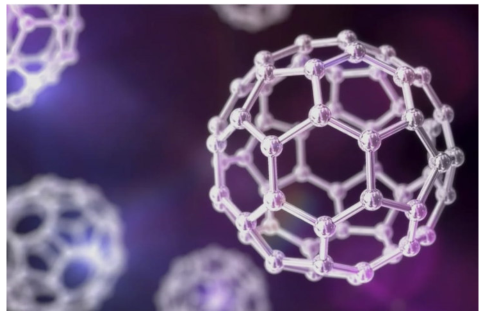
3.7. Applications of Nanoparticles

- Nanoparticles have a wide use in the drug delivery system as they help in improving solubility, stability, and targeting of the drug.
- Hair dyes, cosmetics, and nanoparticles increase the color stability, UV protection, and permeability of the skin.
- In the field of cancer treatment, nanoparticles facilitate the targeted delivery of anti-cancer medications with minimal toxicity to normal cells.
- Imaging applications: Nanoparticles have been used as medical contrast agents in Magnetic Resonance Imaging, Computed Tomography scans, and Fluorescence Imaging.
- Antimicrobial nanoparticles such as silver and zinc oxide nanoparticles have antifungal, antibacterial, and antiviral properties.

3.8. Advantages & Disadvantages

Nanoparticles provide high bioavailability because they have increased solubility and absorption rates. They offer controlled and sustained release of drugs.

On the other hand, toxicity is a concern in photo-nano catalysts because of the possible accumulation of particles, especially metallic nanoparticles, in biological systems. Issues of particle stability, aggregation, and drug release are still a concern.



4. PART B: NANOFIBERS

4.1. Definition and Properties

Nanofibers have diameters at a nanometre scale and high length/diameter ratios. Since nanofibers have a very small size, they have physicochemical properties that are not seen at micro- and macro-fibre levels. Some of the most noticeable properties presented by nanofibers are their high surface area to volume ratios, high porosity, and increased strength.

The nanofiber possesses a higher surface area to volume ratio. This feature helps in greater interaction between the nanofiber and the adjacent matter, such as body fluids. Moreover, the feature helps adsorb large amounts of drugs effectively. This leads to the development of nanofibers as successful carriers for delivery systems. Moreover, this feature helps in greater attachment and growth of cells for applications in tissue engineering.

Nanofibers have high porosity. This is due to a network of pores that enable easy transfer of gases, nutrients, and wastes. This is very important in applications such as bandages and tissue supports. Contrary to being lightweight and porous, nanofibers can also be very strong and elastic, depending on the composition and manufacturing technique. This makes it possible for nanofibers to endure mechanical stress.

4.2. Types of Nanofibers

Nanofibers are categorized depending on the material of which they are made; these include polymeric nanofibers, ceramic nanofibers

- Polymeric nanofibers are the most widely used form of nanofibers. They are made from natural as well as synthetic polymers like chitosan, gelatin, collagen, polycaprolactone (PCL), polylactic acid (PLA), and polyethylene oxide (PEO). Polymeric nanofibers are widely used owing to their biocompatibility and simplicity of processing. They find applications in biomedical and pharmaceutical fields like wound care, tissue engineering, and controlled drug delivery systems.
- Ceramic nanofibers are made from inorganic materials such as alumina, silica, titanium dioxide, and zirconia. The ceramic nanofibers have properties like heat resistance, chemical resistance, and high tensile strength. In turn, they have a range of applications such as heat filtration, catalysis, and insulation.
- Carbon nanofibers have high electrical conductivity, mechanical strength, and thermal stability. Carbon nanofibers have applications in electrochemical energy storage devices, sensors, electromagnetic shielding materials, and high-strength reinforcement materials. In biomedicine, carbon nanofibers have potential applications in tissue engineering for nerves and biosensing.
- Composite nanofibers are made by combining two or more materials in an effort to improve or tailor specific properties.

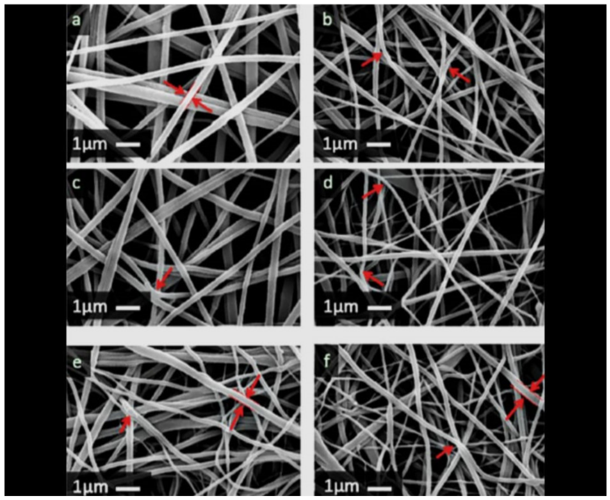


Fig 3. *Nanofibers*

4.3. Procedures of Preparation

Several methods have been employed for preparing nanofibers. These have different advantages.

- Electrospinning is currently the most popular and flexible procedure used for the production of nanofibers. This process uses a high-voltage electric field to extrude a solution or melt of a polymer, resulting in the production of nanofibers deposited on a grounded surface. This procedure is very commonly used in biomedical and pharmaceutical research due to its precision regarding fibre diameter, morphology, and porosity.
- Phase separation is a method whereby a homogeneous solution of the polymer is heat-induced to separate into two phases with a higher and lower concentration of the polymer. Solvent extraction leads to the formation of a nanofibrous structure. This process is widely used to synthesize nanofibers with a high level of porosity to be used as substrates for tissue engineering.
- Self-assembly is a bottom-up technique where molecules automatically form nanofibers. This process occurs due to weak interactions such as hydrogen bonding and electrostatic interactions. This technique helps achieve molecular-level control over structure, but processing requirements make it difficult.
- The drawing process: The process involves mechanically extruding a polymer melt or solution to acquire nanofibers.

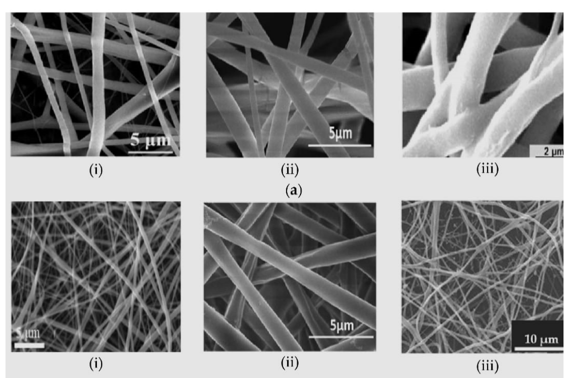


Fig 4. *Nanofibers*

4.4. Characterization of Nanofibers

Characterization of nanofibers is required to assess their structure, mechanical properties, and functionality.

The diameter analysis is usually performed by image analysis software for the determination of size distribution and uniformity. Fiber diameter is a key factor in drug loading, mechanical strength, and biological interaction.

SEM and TEM are employed to study morphology, surface structure, and internal architecture. While SEM gives surface details, TEM can provide high-resolution information on the internal structure.

Mechanical testing of strength determines the tensile strength, elasticity, and flexibility of nanofibrous mats, which are some of the important parameters for wound dressings and scaffolds.

Porosity studies establish the pore size, pore distribution, and overall porosity that affect properties such as permeability, cell infiltration, and mass transport.

4.5. Applications of Nanofibers

Nanofibers also find applications in various ways. In the dressing of wounds, nanofibers ensure a moisturized environment. In the field of tissue engineering, nanofibers act as a scaffold in the dressing of wounds.

Nanofibers can be applied to drug delivery systems where they allow for the controlled and sustained release of a drug. For filtration membranes, nanofibers have high filtration efficiency with smaller pore sizes and higher surface areas. Another application of nanofibers can be seen in smart fabrics where they can be combined for antimicrobial, conductive, and protective functions.

4.6. Advantages and Limitations

Nanofibers have numerous benefits; these include large surface area, higher drug loading capacity, and better biological interaction. Despite all this, problems associated with production at a larger scale and higher production costs make them limited for use in a commercial setting.

5. FUTURE PRESPECTIVE

5.1. Personalised Medicine

Nanoparticles, nanofibers, and nanofibers have a great relevance to advancements in personalized medicine, where a patient will receive treatments depending on their genetic makeup.

Examples:

Nano-carriers laden with patient-specific therapeutic mixtures

Nanofiber Dressings for the Controlled Release of Growth Factors Depending on Wound Conditions

Targeted delivery systems that engage certain biomarkers

Nanomedicine personalized will provide improved efficacy, fewer side effects, and adaptability based on feedback in real time.

5.2. Scalable Manufacturing

One of the most important future applications will be the scaling up of nanomaterial production that is both reproducible and economic. The following are

Maintaining equal or similar dimensions for all particles or fibers on an industry

Cost considerations in high-precision manufacturing

Pharmaceutical grade batch regulatory compliances

5.3. Emerging solutions

Standardized continuous flow reactors

The process Automated electrospinning systems

Green Synthesis with Automation

These promising developments seek to fill the divide between research innovations and scaled-up manufacturing.

6. CONCLUSION

Nanoparticles and nanofibers are currently in an advanced stage of design, defined by the following:

Intelligent and response to stimuli behaviours

Integration of AI for Predictive Design

Environmentally benign synthesis methods

These innovations provide optimal drug-delivery systems, diagnostic tools, and functional materials.

6.1. Importance of Nanoparticles and Nanofibers

These unique properties, which include high surface-volume ratios, tunability, and multifunctionality, make them useful for:

Specific and controlled drugs

Enhanced material properties for biomedicine

Better environmental and industrial uses

6.2. Possible Impact on Health Care Industry:

Nanotechnology will:

Facilitate next-generation therapies (precision oncology, Regenerative medicine

Reduces treatment costs and side effects

Provide momentum to new products in biotechnology, textiles, filtration, and energy

Intelligent, sustainable, and AI-integrated nanomaterials hold a promise of a forthcoming era of nanotechnology-based engineering that will revolutionize world-class healthcare and production.

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