ejpmr, 2024, 11(7), 221-228

SJIF Impact Factor 7.065

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

Review Article

ISSN 2394-3211

EJPMR

NANOTECHNOLOGY: EMERGING ERA FOR AUTOIMMUNE DISEASES

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Article Received on 07/05/2024 **Article Revised on 27/05/2024** **Article Accepted on 17/06/2024**

ABSTRACT

The therapy options for autoimmune illnesses, in which the body's immune system attacks its own tissues, are being completely transformed by nanotechnology. Conventional treatments for these conditions depend on widespread immunosuppression, which frequently has unfavourable side effects. The development of nanotechnology presents a fresh and exciting substitute. With sizes ranging from one to 100 nanometres, nanoparticles provide a novel approach to immunological regulation, targeted medication delivery, and the development of antigen-specific tolerance. Their tiny size enables accurate interactions at the cellular level, which makes it possible to diagnose diseases early and develop customized medicines. The continuous medication release provided by these particles—which are usually biodegradable—is especially helpful in the treatment of long-term autoimmune diseases. Nanoparticles can transport therapeutic compounds directly to the region of action, limiting off-target effects and optimizing therapy efficacy, by accurately targeting afflicted tissues or cells. Additionally, they may be able to control immunological responses and the hyperactive immune system that characterizes autoimmune disorders. Despite these encouraging prospects, more investigation via thorough study, clinical trials, and regulatory clearances is necessary to fully realize the promise of nanotechnology in treating autoimmune illnesses. For those suffering from autoimmune diseases, this new age of nanotechnology-driven medicines has the potential to greatly improve treatment results and quality of life. The search for these breakthroughs might result in safer, more focused, and more potent therapies, bringing in a revolutionary period in the treatment of autoimmune diseases.

KEYWORDS: Nanotechnology, Autoimmune Diseases, Targeted Drug Delivery, improving patient Therapies, Immunomodulation.

INTRODUCTION

Nanotechnology

Nanotechnology, originating from the Greek word "Nano," meaning dwarf, involves applying principles of engineering, electronics, physical and material science, and manufacturing at a molecular or submicron level. It operates within the range of 0.1nm to 100nm, showing promise in biomedical applications, gene therapy, drug delivery, imaging, and drug discovery.

Quantum mechanics and special nanoscale features are explored in nanotechnology. It includes a wide range of endeavours such as nanotechnology, self-assembly, and molecular manufacturing. With over 500 Nano-based goods available and a $1 trillion worldwide market expected by 2015, the sector is flourishing. Its combination with biotechnology is poised to revolutionize medicine by producing innovative medications, biomedical equipment, and answers to health-related problems.

Nanotechnology in Drug Delivery: Over the past decade, nanotechnology has significantly impacted drug delivery systems for small molecules, proteins, and DNA. It has given rise to new fields, providing strategic tools for the pharmaceutical industry to expand drug markets.[1]

Advantages of nano drug delivery

Increased surface area, enhanced solubility, faster dissolution rates, improved oral bioavailability, rapid onset of therapeutic action, reduced dose requirements, and decreased variability are benefits of utilizing nanotechnology.

The benefits of nanotechnology are

Reformulating blockbuster drugs through novel drug delivery systems can extend their lifespan, enhance patent protection, and reduce costs compared to discovering new molecules, ultimately minimizing the use of expensive drugs.

Key features of nanotechnology

- Research and technology development at the 10 nm –1000 nm range.
- Creation and use of structures with novel properties due to their small size.
- Ability to control or manipulate at the atomic and molecular scale.[2]

Significance of drug Delivery and Targeting

The constraints of conventional therapies are overcome by nanotechnology, which offers chances in medication delivery for illnesses including respiratory, central nervous system, and cardiovascular problems. It's becoming more popular in cancer treatment since it allows for focused medication delivery to tumours with the least amount of harm to healthy cells. Difficulties include drug stability and size restrictions for less strong medications that require larger dosages.[3,4]

Autoimmune diseases

Autoimmune disorders affect around 24 million Americans and 5% of the global population, primarily impacting women in their younger and middle years. Over a hundred diseases, including lupus, diabetes, arthritis, and MS, fall under this category. Diagnosis and treatment remain challenging due to varied symptoms and lengthy lab testing. Current medications often affect overall immunity, while biological therapies face issues with targeting and durability. Nanotechnology shows promise in treating, imaging, and sensing autoimmune diseases, with advancements such as iron nanoparticles in MRI and polymeric nanoparticles for conditions like MS, RA, and Crohn's disease. This approach holds potential to revolutionize disease treatment.[5]

Mechanism of autoimmune disorders

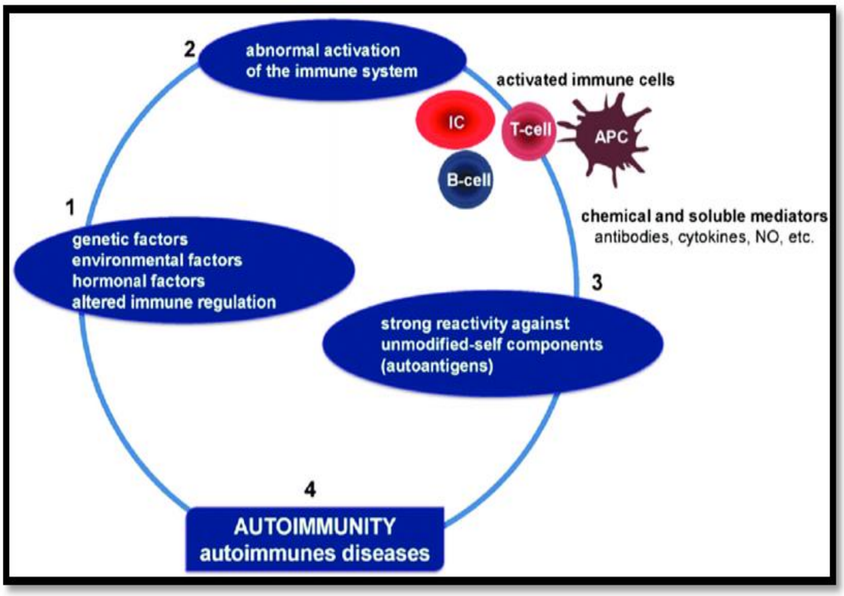

Figure 01: Mechanism of autoimmune disorder.[6]

Diseases involve in autoimmune disorders

1) Type I diabetes

In type 1 diabetes, the immune system attacks insulin-producing cells in the pancreas, leading to high blood sugar levels. This damages blood vessels and organs like the heart, kidneys, eyes, and nerves. Insulin, produced by the pancreas, regulates blood sugar levels.[7]

2) Rheumatoid Arteries (RA)

Rheumatoid arthritis (RA) is an autoimmune disease where the immune system mistakenly attacks healthy cells, leading to inflammation in affected areas of the body. It primarily targets joints in the hands, wrists, and knees, damaging joint tissue due to inflammation.[8]

3) Prairies / Psoriatic arthritis

Psoriatic arthritis is an autoimmune condition where the immune system attacks healthy cells, leading to joint inflammation and overproduction of skin cells. Genetic and environmental factors likely contribute to this immune response. Up to 30% of people with psoriasis experience joint swelling, stiffness, and pain.[9]

4) Systemic lupus erythematous (SLE)

It is an autoimmune disease in which the immune system attacks its own tissues, causing widespread inflammation and tissue damage in the affected organs. It can affect the joints, skin, brain, lungs, kidneys, and blood vessels.[10]

5) Inflammatory bowel disease

Inflammatory bowel disease (IBD) refers to conditions causing inflammation in the intestinal wall. Crohn's disease can affect any part of the gastrointestinal (GI) tract, from mouth to anus. Ulcerative colitis specifically inflames the lining of the large intestine (colon).[11]

Treatment of autoimmune diseases

Application	Description
Targeted Drug Delivery	Nanoparticles encapsulate and deliver drugs specifically to affected immune cells or tissues, reducing side effects. Liposomes or polymeric nanoparticles can gradually release immunosuppressive drugs at disease sites.[12]
Immunomodulation	Engineered nanoparticles modulate the immune system's response by carrying antigens or immunomodulatory agents. They promote immune tolerance, suppress autoimmune responses, or target immune cells to regulate their activity.[13]
Antigen-Specific Tolerance Induction	Nanoparticles induce antigen-specific tolerance, delivering autoantigens or disease-associated antigens to teach the immune system not to attack its own tissues.[14]
Imaging and Diagnostics	Functionalized nanoparticles aid in diagnostic imaging. For example, iron oxide nanoparticles are used in MRI to detect inflammation or lesions in autoimmune diseases. Quantum dots enable precise disease monitoring and early detection.[15]
Biosensors	Nanoscale biosensors detect specific biomarkers associated with autoimmune diseases, allowing for early diagnosis and disease monitoring.[16]
Biodegradable Nanoparticles	Biodegradable nanoparticles release therapeutic agents over time, providing sustained medication release, particularly useful for chronic autoimmune diseases.[17]
Gene Therapy	Nanoparticles deliver small interfering RNA (siRNA) for gene therapy, targeting and silencing genes responsible for autoimmune reactions.[18]
Personalized Medicine	Nanotechnology enables personalized treatment approaches by tailoring nanoparticles and drug payloads to an individual's specific autoimmune profile.[19]

Types of nanotechnology used in autoimmune diseases

1. Dendrimers

Nanoscale molecules known as dendrimers have a distinct, radially symmetric structure made up of distinct, homogeneous, and monodisperse parts, such as an inner shell, an outer shell, and a canter core. Dendrimers offer homogeneity even though conventional macromolecular architectural classes frequently produce polydisperse products. Their biological characteristics, which include minimal cytotoxicity, chemical stability, self-assembly ability, polyvalency, and solubility, make them extremely promising for a range of medicinal applications.

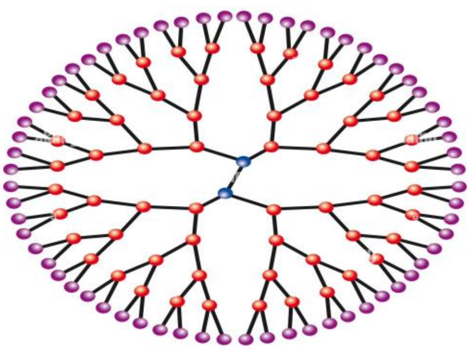

Figure 2: Structure of dendrimers.[20]

2. Liposomes

Liposomes are tiny, spherical vesicles with an aqueous core surrounded by lipid bilayers, usually phospholipids. Because of their capacity to encapsulate medications or other molecules, shielding them from deterioration and enabling targeted distribution to certain tissues or cells, they are extensively employed in drug delivery and biomedical research. Drug release kinetics may be regulated, drug solubility can be increased, and therapeutic effectiveness can be improved with customized liposomes. Among other things, they are used in gene therapy, cancer treatment, vaccine administration, and cosmetic formulations.

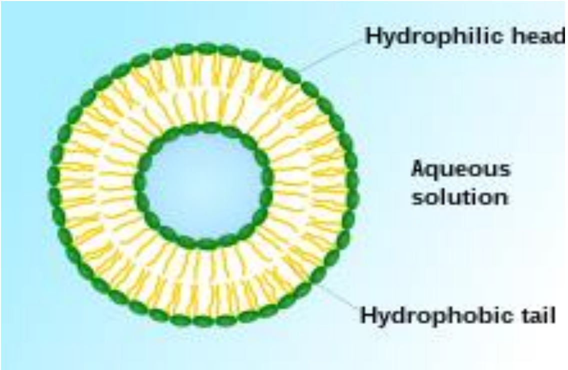

Figure 3: Structure of liposomes.[21,22]

3. Quantum dots

Quantum dots are semiconductor nanocrystals with unique optical and electronic properties. They have a diameter typically ranging from 2 to 10 nanometers. Quantum dots emit light when excited by an external energy source, and their emission wavelength can be precisely controlled by adjusting their size. They find applications in various fields such as electronics, displays, lighting, solar cells, biomedical imaging, and drug delivery. Their small size and tunable properties make them promising candidates for next-generation technologies.

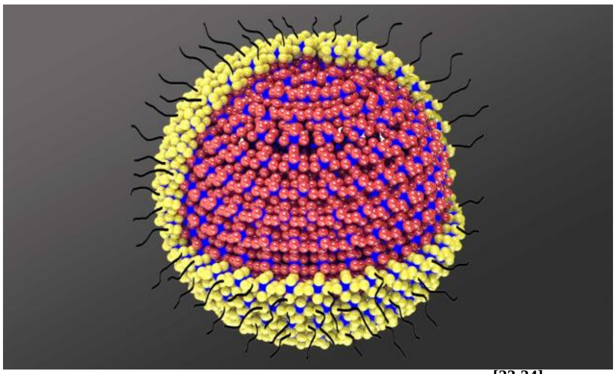

Figure 4: Structure of quantum dots.[23,24]

4. Micelles

Micelles are small spherical structures formed by the self-assembly of amphiphilic molecules in aqueous solutions. These molecules have both hydrophilic (water-attracting) and hydrophobic (water-repelling) regions. In a solution, micelles arrange themselves so that their hydrophobic tails are shielded from the surrounding water, while their hydrophilic heads interact with the aqueous environment. Micelles can encapsulate hydrophobic molecules within their core, making them useful for drug delivery, solubilizing poorly water-soluble compounds, and facilitating their absorption in biological systems. They are widely studied and applied in pharmaceuticals, cosmetics, and various other fields.

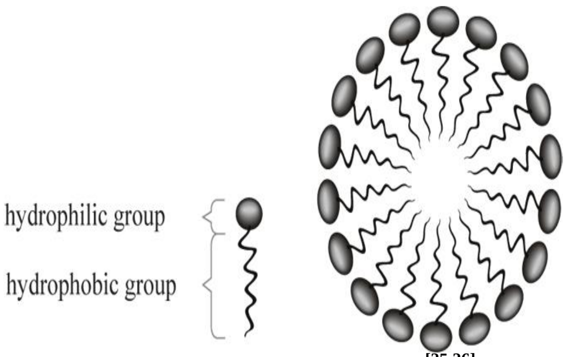

Figure 5: Structure of micelles.[25,26]

5. Nanospheres and Nanocapsules

Solid, spherical nanoparticles called nanospheres and nanocapsules are utilized in medication delivery systems. Drugs are encapsulated in nanospheres for targeted delivery, stability, and controlled release. Nanospheres are composed of inorganic or polymeric materials and range in size from 1 to 100 nanometers. Drugs are contained in nanocapsules, which have comparable advantages and uses in biotechnology, nanomedicine, and pharmaceuticals.

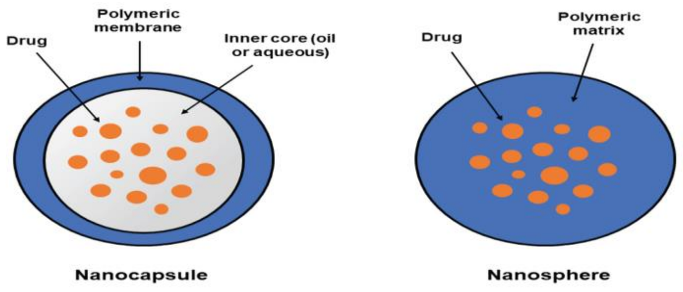

Figure 6: Structure of Nanospheres and Nanocapsules.[27,28]

6. Nanoparticles

Nanoparticles are extremely small particles, usually measuring between one and one hundred nanometers. They may be constructed from a variety of materials, including polymers, metals, semiconductors, and lipids. Because of their tiny size, high surface area to volume ratio, and quantum effects, nanoparticles have special characteristics. They are used in many different industries, including as environmental remediation, electronics, energy, medical, and catalysis. Nanoparticles are utilized in medicine for a variety of purposes, including medication administration, imaging, diagnosis, and treatment. They provide benefits such improved biocompatibility, controlled release, and targeted delivery.

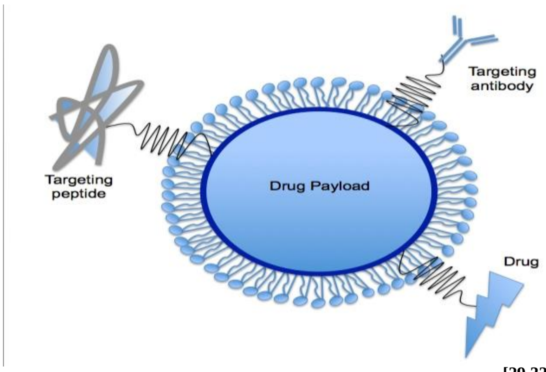

Figure 7: Structure of nanoparticles.[29,32]

7. Polymeric nanoparticles

Synthetic or natural polymers can be combined to create nanoparticles known as polymeric nanoparticles. These nanoparticles' biocompatibility, adaptability, and capacity to encapsulate a broad variety of medications make them often utilized in drug delivery systems. Polymeric nanoparticles can be designed to target certain bodily tissues or cells, regulate medication release kinetics, and enhance drug stability. They have benefits include preventing medication deterioration, lowering adverse effects, and improving therapeutic efficacy. In the fields of biotechnology, nanomedicine, and pharmaceuticals, polymeric nanoparticles are thoroughly studied and used for a variety of medicinal purposes.

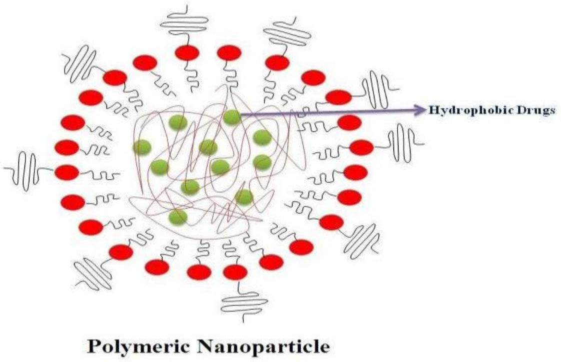

Figure 8: Structure of polymeric nanoparticles.[33,35]

8. Carbon nanotubes

Carbon atoms organized in a hexagonal lattice form the c ylindrical nanostructures known as carbon nanotubes (C NTs).Because of their special structure, they have remark able mechanical, electrical, and thermal capabilities.Ther e are two types of carbon nanotubes: singlewalled (SWC NTs) and multiwalled (MWCNTs), which are made up o f several concentric layers of carbon atos.They are used i n many different industries, including healthcare electron ics, materials research, aerospace, and energy storage.Be cause carbon nanotubes are biocompatible, have a large s urface area, and can pass through cell membranes, they a re being studied in the fields of biomedicine for drug deli very, tissue engineering, biosensing, imaging, andcancer treatment.To ensure their safe and efficient usage in bio medical applications, more research is needed into their p ossible toxicity and biodegradability.

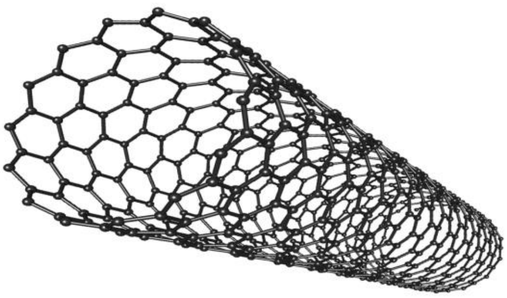

Figure 9: Structure of carbon nanotube.[36]

9. Nanosuspension

A colloidal dispersion of nanoparticles in a liquid, usually water, is called a nanosuspension. These stabilized nanoparticles are usually less than one micron and are designed to avoid aggregating. Pharmaceutical formulations frequently employ nanosuspensions to increase the bioavailability and solubility of poorly water-soluble medications. Nanosuspensions can improve medication absorption in the body, increase drug surface area, and accelerate dissolution rates by shrinking drug particle size to the nanometer scale. Their aqueous solubility makes them very beneficial for the delivery of pharmaceuticals, since they provide benefits in formulation flexibility and simplicity of administration. Drug delivery methods such as oral, parenteral, topical, and pulmonary can benefit from the use of nanosuspensions.

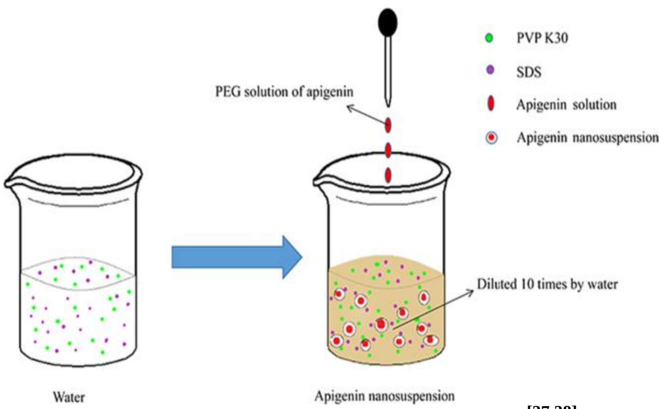

Figure 9: Structure of nanosuspension.[37,38]

CONCLUSION

The use of nanotechnology to the study of autoimmune diseases heralds a bright new chapter in medical history. Nanoparticles are transforming diagnostics and therapy because they specifically target the immune system. By reducing adverse effects, advanced medication delivery improves treatment efficacy. Personalized nanomedicine may be possible thanks to the innovative work of multidisciplinary teams in the field of nanomaterials. Although there are still obstacles to overcome, the advancements in nanotechnology highlight its revolutionary potential in managing autoimmune diseases and provide hope for better diagnosis and therapies.

ACKNOWLEDGMENTS

The authors would like to thanks Kamla Nehru College of Pharmacy Butibori Nagpur.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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