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Review Article

An Overview Of Nanoparticles A Survey Of Characteristics, Advancements And Challenges

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ABSTRACT

Nanoparticles (NPs) are pervasive in our daily lives today as a result of the industry's rapid expansion in the previous ten years. Numerous nanomaterials have been created with medicinal applications in mind. One of these goals is pulmonary illness treatment. The use of colloidal drug delivery systems as drug carriers for the administration of various medications via various routes of administration has received substantial research. For a very long time, systems like polymeric nanoparticles, liposome, and solid lipid nanoparticles have been studied for the treatment of various lung ailments. It appears that nanoparticles could have dual impacts. When nanomaterials are used to develop medicines, their toxic consequences should be taken into account. In order to summarise the dual functions of nanoparticles in treating pulmonary disorders as well as the onset of lung diseases and even secondary diseases brought on by lung damage. We'll also talk about how these impacts are caused by factors like the physicochemical characteristics of nanoparticles.

INTRODUCTION

The last few decades have seen a lot of interest in colloidal drug delivery technologies, particularly nanoparticles. The absorption of nanoparticles by alveolar macrophages, on the other hand, has been found to be inhibited if the particles are smaller than 260nm . Nanotechnology's quick progress has led to ground-breaking uses in a variety of industries, including electronics [1], biosensors [2], medication delivery [3], DNA vaccine adjuvants [4], and others. Even common household items like fullerene and carbon nanotubes, metal-based nanomaterials like metal oxides and quantum dots, and dendrimers, which are branched nanoscale polymers with many potential uses in medicine, are all examples of manufactured nanomaterials [5]. The human body can be exposed to nanoparticles or nanomaterials in a variety of ways, including ingestion, cutaneous contact with the skin, inhalation through

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the respiratory system, injection through the bloodstream, and more [6]. The respiratory system is continuously exposed to the outside world, including airborne microbes (such as bacteria, viruses, and fungi). Numerous lung disorders, including asthma, TB, and lung cancer, are helped by nanoparticles.

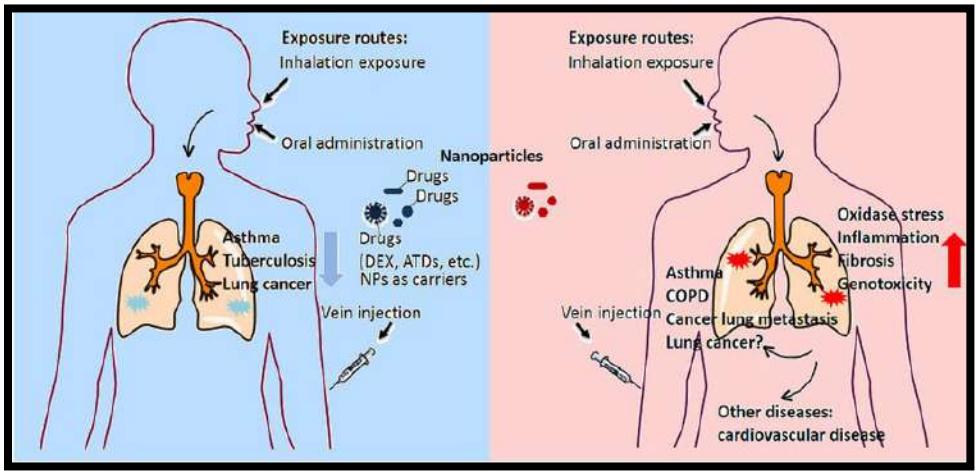

Figure 1 : The role of nanoparticles in pulmonary diseases

Nanoparticles (NPs)

NPs come in a variety of forms, dimensions, and topologies. They could be irregular [7], spherical, cylindrical, conical, tubular, hollow core, spiral, etc. NPs can range in size from 1 to 100 nm in size. Atom clusters is usually recommended if the size of NPs is less than 1 nm. NPs can be amorphous or crystalline, having single or many crystal solids. NPs can be agglomerated or loose [8].

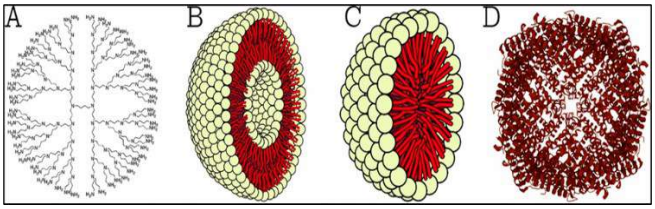

Figure 2: Types of organic NPs: A dendrimers, B liposomes, C micelles, D ferritin

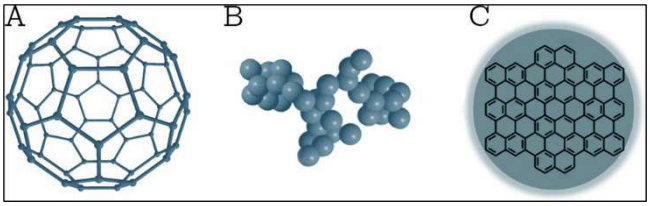

Figure 3: Three Different types of carbon-based NPs. A. C60 fullerene; B. carbon black NPs; and C. carbon quantum dots

Classification of NPs:

NPs are typically categorised into three groups based on their composition: organic, carbon-based, and inorganic [7].

Organic NPs:

This category includes NPs consisting of polymers, lipids, proteins, carbohydrate, or any other organic component [9]. Dendrimers, liposomes, micelles, and protein complexes like ferritin are some of the most well-known examples of this family (Fig. 1). The majority of these NPs are non-toxic, biodegradable, and occasionally even have a hollow core, like liposome's do. Organic NPs are susceptible to electromagnetic and thermal radiation, including light and heat [9]. Additionally, because they are frequently created by non-covalent intermolecular interactions, they are more brittle by nature and provide a pathway for excretion from the body [10]. There are different parameters that determine the potential field of application of organic NPs, e.g., composition, surface morphology, stability, carrying capacity, etc. Today, organic NPs are mostly used in the biomedical field in targeted drug delivery [9] and cancer therapy [11].

Carbon based NPs:

This group of NPs is built up entirely of carbon atoms [9]. Fullerenes, carbon black nanoparticles, and carbon quantum dots are well-known members of this class (Fig. 2). Carbon compounds known as fullerenes have a symmetrical closed-cage structure. In addition to C60 fullerenes, which have 60 carbon atoms organised in the shape of a football [12], C70 and C540 fullerenes have also been described [13]. The strongly fused spherical particle aggregates known as carbon black NPs resemble grapes [14]. Carbon nanoparticles (NPs) less than 10 nm in size make up carbon quantum dots (CQDs) [15].The peculiar characteristics of sp2-hybridized carbon bonds are combined with exceptional physicochemical properties at the nanoscale in carbon-based NPs. Carbon-based NPs are used in a variety of applications, including drug delivery [16], energy storage [17], bio imaging [18], photovoltaic devices, and environmental sensing applications to monitor microbial ecology or to detect microbial pathogens [19]. This is because of their unique electrical conductivity, high strength, electron affinity, optical, thermal, and absorption properties.

Inorganic NPs:

NPs that are not formed of carbon or biological elements belong to this class. The most common examples of this class include semiconductor NPs, metal NPs, and ceramic NPs. Purely composed of metal precursors, metal nanoparticles (MNPs) can be monometallic [20], bimetallic [20], or polymetallic [21]. Bimetallic nanoparticles (NPs) can be created from alloys or created in layers (core-shell) [20]. These NPs have special optical and electrical capabilities because of the peculiarities of the localised surface plasmon resonance [22]. Additionally, some metal NPs have special biological, magnetic, and thermal properties [7].As a result, they become more and more crucial building blocks for the creation of nanodevices with a wide range of physical, chemical, biological, biomedical, and pharmacological uses [23,24]. These applications (and others) are covered in more detail in the review's section on applications. Modern day cutting-edge materials require the regulated synthesis of metal NPs in terms of size, shape, and facet [25].

Concept of Targeted Delivery and in vivo Behaviour of Nanoparticles

Particles with a diameter of less than one micron are referred to as nanoparticles. Numerous different types of nanoparticles have been created as drug carriers for biomedical uses since the early 2000s. Due to their submicron diameters, nanoparticles frequently share their distinctive physical features, and these traits have been used to develop drugs that target particular diseases. Importantly, although having equal total masses, nanoparticles (>1 m) have a greater surface area than micromaterials. It enhances the effectiveness of cellular transport by giving nanoparticles a higher chance to make contact with the nearby tissues and cells [26,27]. Additionally, systemically injected nanoparticles exhibit higher accumulation to the pathological lesions seen in tumours, hemorrhagic illnesses, and inflammatory disorders in vivo [28,29,30]. These results imply that nanoparticles have the perfect characteristics for usage as novel medication delivery systems.

Determinants for the pulmonary Delivery of Nanoparticles

Shape, size, composition, and type of the formulation all play significant roles in the pulmonary delivery of nanoparticles [31, 32, 33]. The main factor affecting the in vivo distribution of the inhaled nanoparticles is specifically the aerodynamic diameter of nanoparticles [34, 35, 36, 37, 38]. Figure (3) [39] depicts the particle size-dependent regional deposition in the lung. Particles greater than 5 to 6 m are typically expelled, however smaller particles can enter the

trachea and bronchial area. Particles at the nanoscale (1 m) can be transmitted to the lower respiratory system, including the alveoli, while ultrafine particles (1-2 m) are typically deposited in the bronchioles. Dendrimers, which are ultra small nanoparticles with a diameter of less than 20 nm, demonstrated effective transport to the alveoli but frequently had poor retention in the lungs because of their quick bloodstream penetration [40,41]. However, with a structural modification, the pharmacokinetics of the nanoparticles can be changed. A dendrimer's bio distribution changed when it was modified with different molecular weights of polyethylene glycol (PEG) polymers because the PEG modification changed the particle size [42]. While modified dendrimers with higher sizes (>78 kDa) collected in the lungs, unmodified dendrimers were quickly absorbed into the bloodstream [42]. Since there was a clear relationship between the size of the nanoparticles and their absorption or retention, the size property needs to be carefully considered for efficient delivery. Since nanoparticles frequently form large aggregates after being discharged from an aerosol or during the delivery inside the respiratory systems, it is therefore imperative to evaluate the real distribution and the bioavailability of the treated nanoparticles [43].

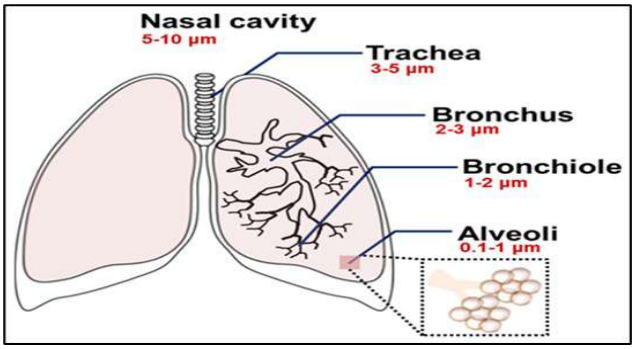

Figure 4 : Size-depended regional deposition of micro-and nanoparticles within the respiratory system after the inhalation (http://www.mdpi.com)

1. Asthma

Asthma, a significant public health issue, is thought to be a chronic inflammatory illness linked to hyper responsiveness of the airways. Asthma's chronic inflammation can cause airways to remodel and undergo ultra structural changes[44]. The damage cannot be fully repaired with the current therapeutic options, such as breathing steroids. The preferred method of controlling asthma is inhaled steroids, however their pharmacological effects are frequently transient. Additionally, its usage has been restricted because of systemic adverse effect

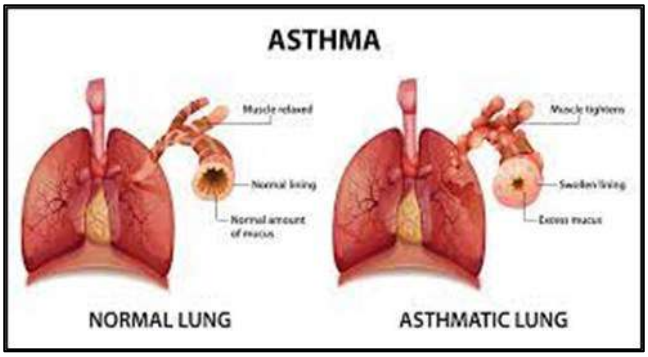

Figure 5: Asthmatic Lung

2. Tuberculosis

The bacillus Mycobacterium tuberculosis is the cause of tuberculosis, which is still a serious infectious illness that has a considerable impact on public health globally. In 2018, an estimated 10 million individuals globally contracted TB, and 1.5 million people died from TB, according to a World Health Organisation (WHO) report [46].Due to ineffective drug penetration into the alveolar macrophages, traditional therapy via systemic administration of anti-TB medicines frequently fails[47,48].Since macrophages are involved in tuberculosis, nanoparticles are a perfect drug delivery system. Liebenberg and Kreuter developed the concept of macrophage targeting to deliver antiviral medication to macrophages, a significant HIV.

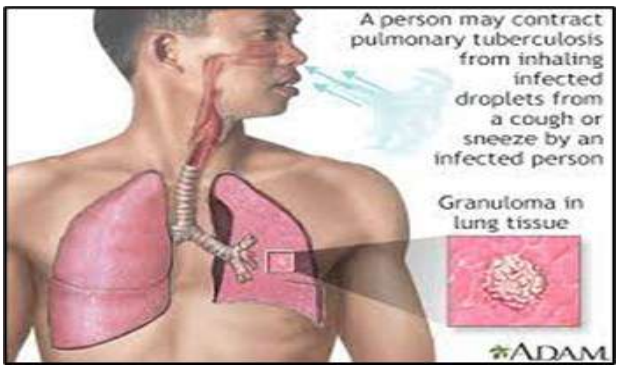

Figure 6: Tuberculosis

3. Lung cancer

One of the most fatal tumours for both men and women is lung cancer [49]. Surgery is usually preceded by chemotherapy. Chemotherapeutic agents do, however, appear to have side effects [50, 51].

Many nanoparticle-based delivery methods are made to precisely deliver chemotherapy medications to tumour cells, reducing their toxicity in the process. Researchers are working on nanoparticle-based delivery systems for miRNAs or siRNAs that silence specific oncogene expression or DNA sequences of tumour-suppressor genes in order to specifically and effectively destroy cancer cells [52, 53]. However, a variety of variables, including physical properties and toxicity, routes of administration, and lung physiology in the context of respiratory disorders, can affect how nanoparticles behave in the lung [54].

FUTURE PROSPECTS

To treat a variety of market indications, nanomedicine was developed. Utilising pharmaceutical technology, we can create drug carriers with enhanced qualities for targeting target areas and attaining significant therapeutic effectiveness. Creating and utilising nanomedicine, as well as taking significant actions to reach therapeutic significance, all go hand in hand. Techniques for particle engineering are essential.

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