Perez, A.P., (2023). J Basic Appl Pharm Sci, 1(1): 104
https://doi.org/10.33790/jbaps1100104

Journal of Basic and Applied Pharmaceutical Science

Nanomedicine in Focus

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Article Details
Article Type: Commentary Article
Received date: 23th November, 2023
Accepted date: 01st December, 2023
Published date: 04th December, 2023

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Citation: Perez, P. A., (2023). Nanomedicine in Focus. *J Basic Appl Pharm Sci, 1*(1): 104. doi: https://doi.org/10.33790/jbaps1100104.

Nanomedicine is the application of nanotechnology in the field of medicine, comprising the utilization of materials at the nanoscale for purposes such as disease diagnosis, prevention, and treatment. This commentary explores some of the applications, challenges, and developments in nanomedicine, with a specific emphasis on the pivotal role of lipid-based nanocarriers in drug delivery systems.

Nanomedicine operates within the scale defined by the prefix 'nano', typically involving materials with at least one dimension ranging from 1 to 100 nanometers. Additionally, materials that fall outside the nanoscale range but still exhibit similar properties or phenomena due to specific dimensions are considered part of nanomedicine [1]. It is worth noting that the properties of these materials differ from the same materials on a larger scale. Moreover, the unique properties of nanomaterials arise from their increased surface area-to-volume ratio as material dimensions shrink, altering their interactions with the environment.

Nanomaterials offer a wealth of diversity in terms of composition and architecture. They can be derived from a wide array of sources, including lipids, polymers, proteins, and inorganic materials. Their structural complexity extends to diverse shapes and sizes. Nanoparticles used for therapy or diagnostics are typically categorized into inorganic and organic types. Inorganic nanoparticles find applications in clinical settings, such as intraoperative lymph node imaging and thermal tumor ablation. They have also been approved by U.S. Food and Drug Administration (FDA) for imaging and anemia treatment [2]. Organic nanoparticles have demonstrated substantial success in clinical applications, including vaccination, hemostasis, long-acting drug delivery systems, and topical agents for systemic delivery through the skin [3].

In drug delivery systems, nanomedicine typically combines appropriate nanocarriers and active pharmaceutical ingredients (API) [4]. The properties of this novel entity are influenced not only by the structure of the API but also by the encapsulating nanocarrier. The advantages of using nanocarriers are numerous: i) enhanced bioavailability for poorly soluble or unstable APIs, ii) precise targeting of APIs to specific sites, reducing side effects and increasing treatment efficacy, iii) user-friendly administration routes, and iv) overcoming various biological barriers, whether they are within target organs or individual cells, enabling capture by cells and intracellular trafficking. For these reasons, nanomedicine has shown exceptional promise in various medical domains. While oncology currently stands as its prominent application, this innovative approach extends to the management of pain, treatment of infections, and vaccination [5]. Indeed, the use of nanoparticles for treating infections is particularly compelling, considering the escalating resistance to antimicrobials and the limited progress in developing new drugs.

However, the promises of nanomedicine are accompanied by formidable challenges. Upon intravenous administration, nanocarriers encounter a series of obstacles hindering their effective and specific delivery to tumors. These challenges include opsonization and subsequent uptake by macrophages, leading to nonspecific distribution in organs such as the spleen and liver. Moreover, the behavior of nanocarriers near vascular walls is significantly influenced by their size and geometry under normal blood vessel flow conditions. High intratumoral pressure, resulting from factors such as interrupted vasculature, aggressive cellular growth, fibrosis, dense extracellular matrices, and impaired lymphatics, presents another hurdle for nanoparticle accumulation in tumors. Cellular internalization and escape from endosomes prove to be formidable barriers, where particle size, morphology and surface decoration determining the internalization pathway and intracellular fate. Additionally, intracellular drug efflux pumps can expel chemotherapeutics, leading to therapy resistance [6]. Therefore, careful consideration of the problem at hand, selection of the appropriate route of administration, and choice of the right nanocarrier are essential when designing a nanomedicine strategy. By addressing these challenges, we can fully unlock the potential of nanomedicine and reshape the landscape of healthcare.

In recent discussions regarding the potential and future prospects of nanomedicine, the undeniable and crucial role of lipid-based nanocarriers cannot be ignored [7-9]. One fascinating example of lipid-based nanocarrier involves liposomes, which have been explored for over three decades as effective carriers for a range of drug molecules. During the 1990s, a significant milestone was reached with the FDA approval of Doxil®, which utilizes pegylated liposomes to encapsulate doxorubicin, extending circulation time and enhancing anticancer efficacy [10]. Another compelling advancement

is found in the FDA-approved formulation of oligonucleotides. Addressing the challenge of nucleic acid instability, Onpattro®, approved in 2018, encapsulates small interfering RNA (siRNA) in a lipid nanoparticle for treating transthyretin amyloidosis [11]. Amid the global COVID-19 pandemic, research into vaccination strategies has accelerated, with two approved vaccines based on encapsulating mRNA in lipid nanoparticles, thereby emphasizing the profound impact of lipid-based nanocarriers in urgent health crises [12]. Notably, novel approaches that co-load more than one API with complementary activities in a lipid-based nanocarrier show promise for treating complex diseases such as cystic fibrosis [13]. These strategies underscore both the significance and versatility of lipid-based nanocarriers.

Nanomedicine has long been considered a promise for treating various diseases. While it is not a new concept, it continues to be a subject of active research and development. The field has made substantial progress, yet there remains much to explore and learn. As we move forward, continued research and innovation will be key to unlocking the full potential of these technologies, offering hope for better and more effective treatments for a wide range of diseases.

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