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Nanomedicine: Targeted drug delivery systems

Introduction

Nanotechnology has many emerging applications including in medicine and pharmaceutical technology. In contrast to current medicine delivery using large doses either taken orally or injected for example, nanotechnology promises to provide targeted delivery of specific medicine directly to certain cell types, organs, cancers, and cross the blood brain barrier to treat neurological conditions. There are many benefits being realized today and many benefits still to be found through continued research and development.

Description

Drug delivery systems (DDSs) include a wide variety of nanoparticle delivery vehicles ranging from metals to many other types of both synthetic and organic materials such as liposomes, graphene particles, and carbon-based particles (Kuskov 2025). These nanoparticles encapsulate the medicine and are delivered to the person or animal through several different mechanisms that include intranasal delivery and injection directly into the target site (i.e. liver, lung, etc.). The application of nanotechnology in medicine delivery is being used in medicine today. Per Tomar et al. (2022), "Liposomal anticancer drugs were the first nanobased formulations approved for cancer therapy by the US Food and Drug Administration (FDA)." The range of medical applications for nanoparticle drug delivery systems is immense and has the potential to have a great beneficial impact on society.

Benefits

Some of the benefits of nanoparticle drug delivery systems are the ability to target specific locations such as the brain or targeting tumor cells without affecting other parts of the body, better absorption of the medicine, reduction of side effects, fewer invasive procedures, and shorter recovery times (Ma, et al., 2024). Another benefit according to Kushov (2025): "a promising way to increase the therapeutic effect is the immobilization of several different drugs into the nano-scaled delivery system at once, which simultaneously affect different targets and have a synergistic effect," which has shown better results in treating leukemia versus single drug delivery. According to Ma, an additional benefit is in the realm of personalized medicine "by enabling the development of nanoformulations that are specifically designed to interact with individual genetic profiles, thereby enhancing therapeutic outcomes." There are also additional cost benefits possible when instead of delivering large doses of a medicine, via pill for example, where much of the treatment is not absorbed, nanotechnology can reduce the amount of medication needed due to the

targeted nature and increased absorption of the nanoparticles. Overall, there are many benefits already being realized by nano drug delivery systems with much more to be found.

Risks and Concerns

A key concern around nano drug delivery systems is how they interact with the human body, which should be addressed in the rigorous regulatory approval process. As mentioned earlier, there are many types of nanoparticles that can be used to encapsulate medicine(s) and each with their own set of risks and benefits. The challenge in research is determining the correct combinations for the intended purpose. According to Ma (2024): "Conducting a comprehensive and reliable evaluation of their toxicity throughout their lifecycle poses a challenge for professionals and organisations alike. This is because the reduction in size or dimensions, particularly to nanoscale in one or two dimensions, can lead to not only novel properties but also potentially unconventional toxicity behaviour." Some questions to address through clinical trials are how the body is handling absorption of the nanoparticle in addition to the medicine, is the nanoparticle reaching its intended target or affecting other parts of the body and is the nanoparticle causing some level of toxicity within the body like inflammation or other unintended side effects.

Another concern is the potential environmental impact of this technology. Like any other emerging technology, assessing the downstream impact of manufacturing nanoparticles and their introduction into the environment is a key risk factor requiring assessment. There could be unforeseen consequences when these nanoparticles interact with wildlife, accumulate in waterways, or are floating through the air and potentially accumulating in respiratory tracts among other risks.

Regulatory and Safety Issues

In the United States, the Food and Drug Administration as well as the Environmental Protection Agency already have regulations in place related to nanotechnology. The FDA's guidance (2022) on using nanomaterials in medical applications includes a recommended risk assessment framework which includes assessment of the concerns mentioned earlier and additional guidance. This is in addition to existing rigorous regulations of new medicines that must be followed to take a new drug to market.

Some challenges of regulating nano drug delivery systems is maintaining global consensus on definitions of nanoparticles and nanomaterials and standardizing risk assessment frameworks. Scientists and policymakers can balance innovation with safety and public trust by being transparent in testing and evaluation of these technologies as they emerge (i.e. new drugs and devices) while remaining flexible in allowing innovation to occur. The FDA's guidance document showcases this flexibility; however, there must be some safety

standard with this new medication delivery system and some assurance to gain public trust. Rather than suddenly making the change from traditional medicine delivery to a “new and improved” delivery system that the public will likely not understand and immediately become wary of, take the time to introduce the technology, its benefits, and the standards for safety before making such a change. This requires some level of safety requirement that goes beyond guidance while maintaining flexibility in research and development.

Policymakers should consider that the benefits of this technology are immense and seek to understand it while ensuring that safety considerations are strong enough to prevent any major misstep. For example, a drug taken to market in a nanoparticle delivery system that does more harm than good as opposed to traditional pill form could have disastrous consequences for public trust in nanoparticle delivery systems.

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