Nanoparticles for Drug Delivery: The Tiny Wonders Transforming Medicine

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TOPIC BACKGROUND

PROPERTIES AND USES OF NANOPARTICLES IN MEDICINE: Nanoparticles (NPs) are tiny particles with diameters ranging from 1 to 100 nanometers. They are emerging as a promising avenue for drug delivery and disease treatment in medicine (Afzal et al., 2022). NPs for drug delivery are made by dissolving a drug and a polymer, lipid, metal, or inorganic material in a solvent. Then, techniques such as nanoprecipitation, emulsion-diffusion, solvent evaporation, or supercritical fluid technology are used to form nanoparticles with desired properties (Makadia and Siegel, 2011). The small size of NPs allows them to enter cells and tissues, making them practical as drug-delivery vehicles. NPs also have a high surface area-to-volume ratio, making them ideal for drugs (Rizvi and Saleh, 2018). The most exciting applications of NPs in medicine is their ability to cross the blood-brain barrier (Pinzon-Daza et al., 2013) shown in Figure 2. Nanoparticle-based drug delivery systems are currently being developed for cancer, cardiovascular disease, and neurological disorders such as Alzheimer's disease and Parkinson's disease. For example, the drug Rivastigmine, loaded on polymeric NPs was shown to enhance learning and memory (Afzal et al., 2022). NPs can be synthesized in many ways. Curcumin is a naturally occurring polyphenol in turmeric with anti-inflammation and anti-cancer properties. However, it has low bioavailability and low water solubility. To overcome these issues, researchers have created curcumin-loaded nanoparticles (Hettiarachchi et al., 2021).

HOW DO NANOPARTICLES WORK IN CANCER TREATMENT? Researchers fill a nanoparticle with, say, a cancer drug. Then, a targeting ligand is attached to the surface of the nanoparticle (Figure 1). These NPs are then injected into the bloodstream. The NPs are engineered to only bind to target cancer cells and not to neighboring healthy cells. Once inside a cancer cell, these NPs are digested, and the drug is released, killing the cancer cell (Institute for Molecular Bioscience, 2017).

WHAT ARE SOME CHALLENGES? The safety and toxicity of nanoparticles are significant concerns in drug delivery. In addition, nanoparticles can be unstable and may lose their drug delivery properties during storage or transportation. Also, obtaining regulatory approval for nanoparticle-based drug-delivery systems can be challenging, as requiring extensive testing to ensure safety and efficacy (Nagati et al., 2022).

FUTURE RESEARCH: The future of nanoparticle research for drug delivery may include advancements in targeted delivery, combination therapies where multiple drugs are delivered through a single NP, personalized medicine based on an individual's genetic makeup, and non-invasive drug delivery (Mitchell et al., 2020).

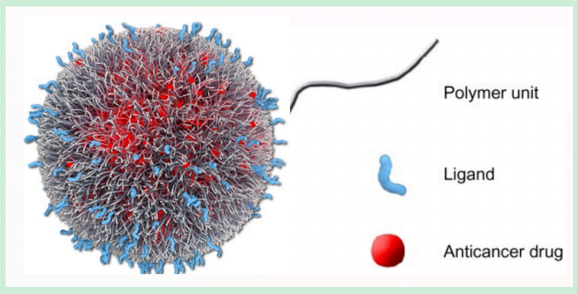


Figure 1: Model of a nanoparticle - image courtesy of BIND Therapeutics

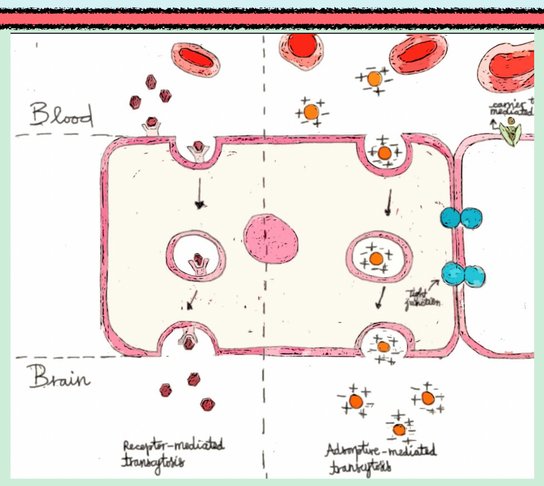


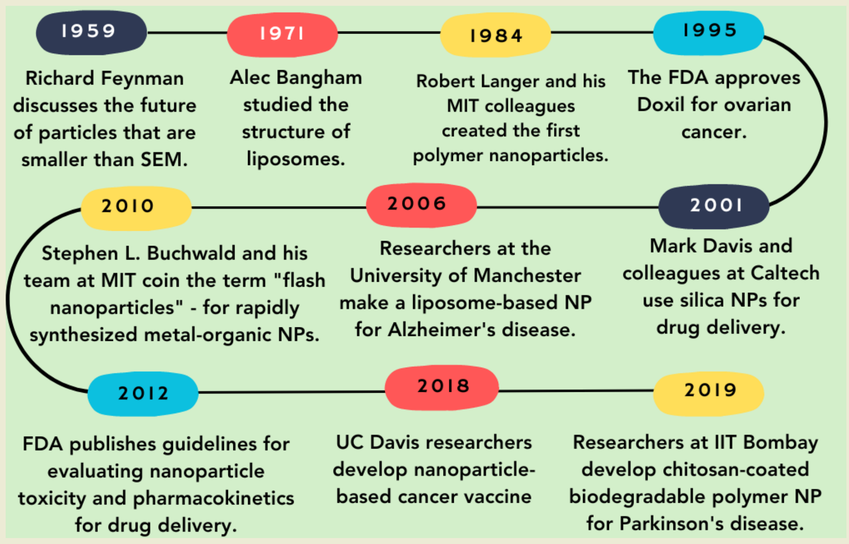
Figure 2: Nanoparticles using different transport mechanisms to cross the blood-brain barrier

ETHICAL, LEGAL, AND SOCIAL ISSUES

While nanoparticles show great potential for improving disease treatment, researchers and policymakers must work together to ensure nanoparticle-based therapies are safe, ethical, and equitable. Ethical issues include managing and communicating the risks associated with engineered nanoparticles in clinical trials. Studies have shown that nanoparticles can cause oxidative stress, inflammation, and cell death and can translocate to other body parts, including the brain (Khanna et al., 2015). Social concerns include the potential for unfair competition due to the misuse of nanoparticles for physical or mental enhancement. There is a risk that nanoparticle-based therapies could become expensive and thus accessible to only those who can afford them, creating disparities in healthcare access. Legal concerns involve the safe production, disposal, and risks associated with diverse nano-materials used in drug therapies (Resnik and Tinkle 2007a)

The toxicity and safety concerns of nanoparticles depend on various factors such as size, shape, surface chemistry, and dose. Different physical and chemical properties can lead to unexpected biological interactions and toxicity (Sukhanova et al., 2018). Thus nanoparticles can behave very differently in an organism than in a cell culture. Each type of nanoparticle needs a subjective assessment to evaluate its safety. Results from animal studies may not always translate to humans. Government agencies should sponsor longitudinal studies to assess the effects on human health (Resnik and Tinkle 2007b). Proper disposal of nanoparticles is necessary to prevent environmental exposure. Despite these concerns, nanomedicine has made significant strides in medicine.

TECHNOLOGICAL TIMELINE



Fun fact: The use of nanoparticles dates back to 9th century Mesopotamia when artisans used them on the surface of the pots to generate a glittering effect.

RESEARCH AND ECONOMIC IMPACT

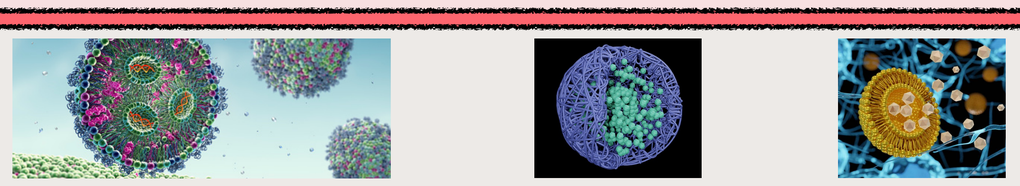
PRODUCTS IN MARKET: Nanoparticle-based drug delivery systems have led to the development of biotech products: For example, Paclitaxel is a chemotherapy drug used to treat breast, ovarian, and lung cancer. The nanoparticle-based formulation of Paclitaxel is known as Abraxane. Doxil and Onivyde are other FDA approved products for cancer treatment (Yan et al., 2020). The Pfizer-BioNTech COVID-19 vaccine uses lipid nanoparticles to deliver mRNA strands that encode the spike protein (Khurana et al., 2021).

PIONEERS IN TECHNOLOGY ADVANCEMENT: The American physicist and Nobel laureate Richard Feynman introduced the concept of nanotechnology in a lecture, "Plenty of Room at the Bottom," in 1959. Companies in this space include Abraxis BioScience, Bind Therapeutics, and Nanosphere Health Sciences (Hartshorn et al.). In addition, the Hammond Lab at MIT, Lam Lab at UC Davis, CNSI lab at UCLA, Mitragotri Lab at Harvard, and NIH are also researching nanoparticles for drug delivery applications.

MARKET OPPORTUNITY: According to a report by Grand View Research, the global market for nanoparticle-based drug delivery systems is expected to reach $300 billion by 2028, growing at a compound annual growth rate (CAGR) of 21.8% during the forecast period (Research and Markets, 2022). The consumer indirectly drives innovation by expressing demand for more effective and targeted drug therapies.

ADVANTAGES: Benefits of nanoparticles for drug delivery includes improved drug efficacy, prolonged release, and targeted delivery to specific tissues or cells. Nanoparticles can also protect drugs from degradation and extend their half-life in the body, reducing the frequency of dosing required. Unlike nanoparticles, conventional drugs for neurodegenerative diseases cannot penetrate through the blood-brain barrier (Khan et al., 2019).

GOVERNMENT REGULATION: In the United States, FDA (Food and Drug Administration) has established toxicity studies and pharmacokinetic evaluations to evaluate the safety and efficacy of nanoparticle-based drugs. In addition, EPA (Environmental Protection Agency) oversees issues like safe disposal, and the NIST (National Institute of Standards and Technology) provides guidelines for the use of nanoparticles in clinical studies (Petersen et al., 2022).



Lipid nanoparticles for mRNA vaccine | Polymer nanoparticles | Liposome nanoparticles

Figure 03: Types of nanoparticles. Image source: https://www.istockphoto.com/

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