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Review Article
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NANOPARTICLES (NPS) BASED DRUG DELIVERY SYSTEM FOR CANCER THERAPY

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Abstract
Nanoparticle-based drug delivery systems represent a breakthrough in modern medicine, offering a promising strategy for targeted, controlled, and efficient cancer therapy. Cancer remains one of the leading causes of death worldwide, characterized by complex pathophysiology. Traditional therapeutic approaches such as chemotherapy, radiation therapy, and immunotherapy, though effective to some extent, face significant limitations including poor selectivity, systemic toxicity, and the development of multidrug resistance, which hinder successful treatment outcomes. The advent of nanotechnology has revolutionized cancer diagnosis and therapy by enabling site-specific delivery, improved drug sstability, and enhanced therapeutic efficacy. Various nanocarriers-such as liposomes, polymeric nanoparticles, dendrimers, and metallic nanoparticles-have been widely explored for applications in chemotherapy, immunotherapy, and gene therapy. Despite existing challenges related to large-scale production, biocompatibility, and long-term safety, nanoparticle-mediated drug delivery continues to advance rapidly. Future research is expected to focus on personalized nanomedicine, smart and multifunctional nanocarriers, gene-editing nanoparticle systems, and environmentally friendly ("green") nanotechnology for safer and more effective cancer treatments. This review highlights the different types of nanoparticles and their targeting mechanisms in cancer drug delivery systems.

Keywords: *Nanoparticles, Targeted Drug Delivery, Cancer Therapy, Nanocarriers, Nanomedicine, Controlled Release*

INTRODUCTION

Targeted drug delivery is a method used to send medicine directly to the part of the organs in the body that needs it, like a tumour or an infected area. This helps the drug reduces side effects on healthy parts of the body. One way to do this is by attaching the medicine to tiny particles called nanoparticles. These nanoparticles are so small that you can't see them without a powerful microscope they range in size from 10 to 1000 nanometers (for comparison, a human hair is about 80,000 nanometers wide!). To work well, these drug delivery systems need to stay in the body long enough to reach the right cells or tissues. They also need to avoid being destroyed too soon by the immune system. The medicine can be mixed into, attached to, or placed inside these nanoparticles in different ways. Depending on how they're made, the nanoparticles can form into nanospheres (solid particles with the drug throughout) or nanocapsules (tiny containers with the drug inside a shell or membrane) [1].

Classification of Nanocarriers

The three different types of nanoparticle drug delivery system was classified based on type of fabrication of nanoparticle and Selection of the nanocarriers type as well as their composition depends upon the disease and the application for which it is to be used [2[fig1]]. Here in these Review article we see CHITOSA, SILICA.

NANOPARTICLES, POLYACTIDE COGLYCOLIC ACID

1.CHITOSA (Natural polymer).

It is natural carbohydrate polymer which is low cost,biodegradable, low toxicity in body .The fabrication of chitosan is conducted in mild conditions as chitosan is soluble in acidic solution at room temperature and no heat is required. A large quantity of drug can given using chitosan drug delivery system and fabrication method used in chitosan nanoparticle was inotropic gelation method, emulsification solvent diffusion method, polyelectrolyte complex method.

Chitosan nanoparticles are used in cancer therapy to target tumors through passive targeting (EPR effect)and, active targeting (binding to cancer-specific molecules), and physical targeting using stimuli like heat or pH changes [3].

2. Silica Nanoparticles (Inorganic)

Silica xerogels are used in drug delivery because they are biocompatible, porous, and easy to modify. However, mesoporous silica nanoparticles (MSNs) are even better. MSNs have a larger surface area for holding drugs, their size can be adjusted to control drug release, and their surface can be easily modified for better targeting. They can also be combined with magnetic or glowing materials for drug delivery and imaging [4]. and there fabrication methods used was solution based method for MSNs synthesis, Evapouration induced self assembly method and the application was Mesoporous silica nanoparticles (MSNs) loaded with a tumor-suppressing mRNA and the drug Oxaliplatin (OXL), called OXmi-HMSN, showed strong anti-cancer effects against colon cancer. The particles were designed to target cancer cells using hyaluronic acid and improve mRNA loading with PEI. They were small enough (138 nm) for passive targeting. The drug was released more slowly due to the PEI layer, but the particles had better uptake by cancer cells and showed the highest tumor suppression in mice. Blank particles without drug or mRNA were safe to cells [5].

3. Polylactide-co-glycolicacid (PLGA) nanoparticles (synthetic)

PLGA nanoparticles are biodegradable and safe polymer used to make nanoparticles for cancer treatment. It allows controlled drug release and works well with body tissues. These nanoparticles can be modified for better targeting, carry different cancer drugs, and release them in various ways. Studies show PLGA nanoparticles are effective and have fewer side effects, making them a promising option for cancer therapy [6]. Fabrication of PLGA includes Emulsion evaporation method, salting out method, non precipitation method, and the Applications of PLGA nanoparticles are often used with active targeting because passive delivery (EPR effect) is not always enough to reach tumors. To target cancer cells betterly, special molecules like hyaluronic acid (HA) are added to the surface of the nanoparticles. HA binds to CD44 receptors, which are found in high amounts on some cancer cells. A study used HA-coated PLGA nanoparticles use to deliver the drug paclitaxel (PTX) for treating triple-negative breast cancer. The particles were made using a simple method and adjusted using different ingredients to improve their size andalso drug-carrying ability. The best version had small size (~250 nm), high drug loading, and strong release of PTX. HA-coated nanoparticles released the drug faster and entered cancer cells better than uncoated ones, likely due to the HA binding to CD44. This made the treatment more effective. Another active targeting method is using external tools, like a magnetic field, to help guide the nanoparticles to tumors [7-8].

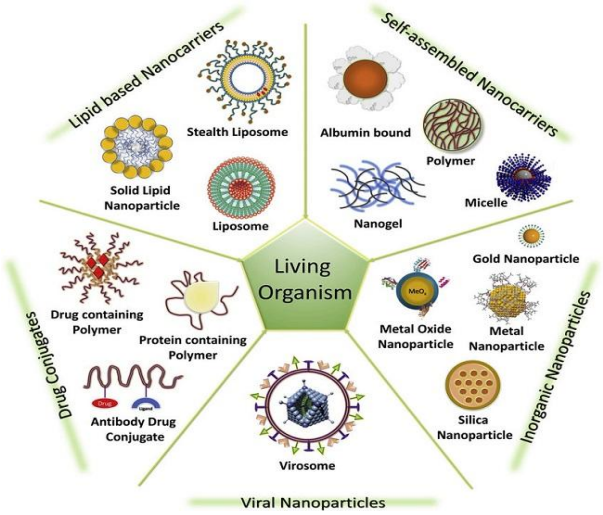

Fig1: Classification of Nanocarriers

The targeting strategy and intracellular uptake pathway. Targeted drug delivery using nanoparticles usually happens in three main steps. First, the nanoparticles attach to specific receptors on the surface of target cells. Next, they enter the cells through a process called endocytosis. Finally, they release drug inside the cells, either in the cytosol or at cell membrane, by interacting with the cell's outer layer. These tiny particles are part of a growing field called nanomedicine, which is changing how we diagnose, treat, and prevent diseases. Nanomedicine technologies can turn scientific discoveries from genetics and protein research into useful treatments for patients. Nanoparticles can also copy or change natural biological processes like fighting infections or helping damaged tissue heal. Examples include carbon nanotubes, DNA-based machines, nanofibers, and tiny silicon chips used to deliver drugs or perform lab tests. Scientists are especially interested in using biodegradable polymers to make nanoparticles because they can release drugs slowly, protect delicate molecules like proteins and DNA, and send drugs to specific parts of the body, such as in tissue repair [9].

To understand how nanoparticle (NP) carriers interact with cancer cells and tumors, it is important to explore their targeting mechanisms. These mechanisms are

mainly divided into two types: passive and active targeting fig 02 [10].

PASSIVE TARGETING

This targeting method uses the enhanced permeability and retention (EPR) effect, where nanoparticles (NPs) build up in tumors because ofleaky blood vesselsandpoor lymphatic drainage. These conditions allow drug-loaded NPs to stay in the tumor area longer, making the treatment more effective. The leaky vessels have tiny openings (fenestrations), and the weak drainage system fails to remove the particles, helping them stay in place. Also, in situations likelow oxygen (hypoxia)or inflammation, the blood vessel walls become even more permeable, allowing more nanoparticles to enter the tumor [10-11].

ACTIVE TARGETING

Nanoparticles use ligands like antibodies or folic acid to bind specific receptors on cancer cells, this allow precise drug delivery through receptor-mediated endocytosis. This increases drug concentration at the tumor and reduces side effects [12]. Active targeting uses nanoparticles coated with special ligands like transferrin, folate, or antibodies that bind to receptors found in high amounts on cancer cells. This helps the nanoparticles enter the cells more effectively, improving drug delivery and reducing side effects. Some nanoparticles also target nearby blood vessels or respond to acidic tumor environments to release drugs. Factors like size, ligand type, and delivery method affect how well this strategy works [13-14].

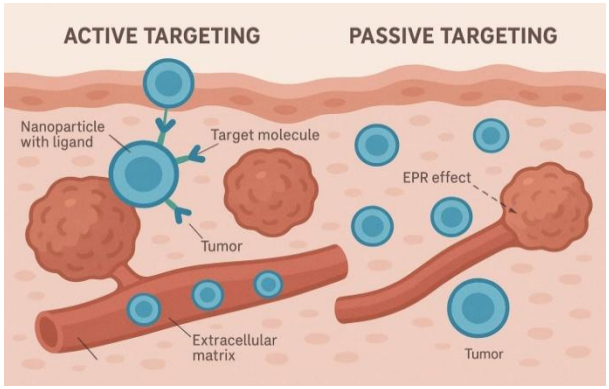

Figure 02: Intracellular uptake pathways

NANOPARTICLES IN CANCER THERAPY

NPs have been studied for several medical uses, such as delivering drugs or genes to tumors and acting as imaging agents. Different types of nanomaterials organic, inorganic, lipid-based, glycan-based, and synthetic polymers have been developed to create better cancer treatments. This study show how NPs are used in cancer therapy, particularly in drug delivery methods. NPs can help improve drug solubility and stability, act as surface coatings for stealth nanoparticles, and boost drug bioavailability and effectiveness through different delivery routes [15-16]. Nanoparticles mainly delivering medicine directly to tumors, helping the body fight cancer, transporting genetic material to cancer cells. And smart drugs made from bacterial materials [17].

Nanoparticles (NPs) have significantly transformed the landscape of cancer therapy by offering a platform for precise, controlled, and efficient drug delivery. Unlike conventional chemotherapeutic approaches, which often suffer from poor targeting and high systemic toxicity, nanoparticle-based systems are engineered to improve the selective accumulation of therapeutic agents in tumor tissues through mechanisms such as enhanced permeability and retention (EPR) and active targeting using ligands. This targeted delivery reduces off-target effects and minimizes damage to healthy tissues, thereby enhancing patient safety and treatment tolerability. Moreover, NPs can be designed to release drugs in response to specific stimuli (such as pH, temperature, or enzymes), allowing controlled and sustained drug release at the tumor site. Their structural ability to adapt and supports the co-delivery of multiple agents such as chemotherapeutics, genes, or immunomodulators enabling combination therapies that can overcome drug resistance and improve therapeutic outcomes. In addition, some nanoparticles can be functionalized for diagnostic imaging, creating theranostic systems that integrate therapy and monitoring in a single platform. As a result, the use of nanoparticles addresses several critical challenges in cancer treatment, including poor drug solubility, non-specific biodistribution, and rapid drug clearance. Overall, NPs offer a promising and multifaceted strategy to enhance the effectiveness and specificity of cancer therapeutics, thereby contributing to more personalized and less toxic treatment regimens [1-18].

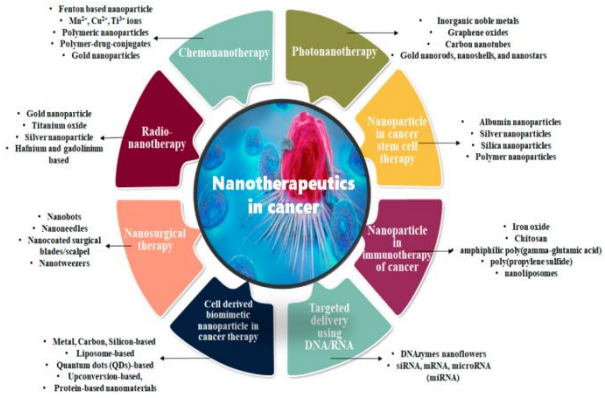

Fig 3: Nanoparticles in cancer Therapy

NANOPARTICLE- MEDIATED DRUG DELIVERY SYSTEM IN CANCER THERAPY

Nanoparticle mediated drug delivery; a innovation aims to sharpen the effectiveness of cancer treatment. In practice these sub microscopic particles nanoparticles act, as vehicles that ferry drugs into the heart of tumor cells. This approach sidesteps the drawbacks of chemotherapy: lackluster solubility, uneven distribution, across the body and the notorious harsh side effects. By steering the drug's pathway and confining its activity to the intended site nanoparticles sharpen the focus of therapy making it both more targeted and more successful. Because of the permeability and retention (EPR) effect they naturally accumulate in tumor regions. They can be engineered to specifically recognize and bind to cancer cells, which make drug delivery more precise [19].

CONCLUSION

Targeted drug delivery using nanoparticles represents a major advancement in modern cancer therapy. By enabling drugs to reach specific tissues or tumor sites with high precision, this technology significantly reduces side effects and enhances treatment efficiency. Various nanocarriers such as chitosan, silica nanoparticles, and PLGA nanoparticles have demonstrated unique advantages in terms of biocompatibility, controlled drug release, and targeted delivery. Nanoparticles operate through passive targeting (via the Enhanced Permeability and Retention effect) and active targeting (through ligand–receptor interactions), allowing more selective drug accumulation in tumor cells while sparing healthy tissues. Their design flexibility enables them to carry multiple therapeutic agents, provide sustained drug release, and even combine diagnostic and therapeutic functions (theranostics). Overall, nanoparticle-mediated drug delivery systems have transformed cancer treatment by improving drug bioavailability, stability, and tumor specificity. These systems pave the way for personalized, efficient, and less toxic cancer therapies, marking a promising future in nanomedicine and oncology research.

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