“EXPLORING NANOPARTICLE THERAPIES IN BREAST CANCER TREATMENT.”

By

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Declaration

It is hereby declared that

1. The thesis submitted is my original work while completing my degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material that has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

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Approval

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Ethics Statement

No animals or humans were harmed during this study.

Abstract

Breast cancer is one of the leading cancers in women, which may occur at any age. Traditional treatments such as chemotherapy, radiotherapy, or surgery are being replaced by nanoparticle-based therapies. As nanoparticle therapies are next-generation treatments, they have fewer side effects than other treatments.

Nanoparticles can carry medicines directly to the cancer cells, which helps to reduce damage to the normal tissues and makes the treatment more specific. Different types of nanoparticles are: gold particles, metallic and metal-oxide nanoparticles, magnetic nanoparticles, liposomes, nanobubbles, and polymer-based particles, which can carry drugs and respond to changes in tumor characteristics like pH, enzyme, light sensitivity, and others. These particles work in different ways, for example, stopping cancer cell growth, blocking cancer cell signaling, and helping the immune system against cancer cells.

However, there are challenges with nanoparticle use in breast cancer treatment, but the future of this can be very promising with focused research work, as the therapy has higher effectiveness in Oncogenic cells.

Keywords: Nanoparticles; Breast Cancer; Treatment; Oncogenic cells; Tumor.

Dedication

I want to dedicate this to my husband, who inspires me to do something for myself and always appreciates me.

Acknowledgement

In the name of Allah, firstly, I want to thank my supervisor, Dr. Sabrina Sharmin Miss, for trusting me and giving me the opportunity to work with her. She was always my idol for being a humble person. Her guidance helped me to do this project a lot. Hope all the best wishes for her. Secondly, I want to thank my parents, who gave me the floor to do something for myself and always appreciate my small steps. Last but not least, I want to thank all of my loving friends who believed in me.

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List of Acronyms

MDR	Multi-drug resistance
EPR	Enhanced Permeability and Retention
NP	Nanoparticle

Chapter 1

Introduction

1.1 Background

Breast cancer is still one of the main causes of cancer-related morbidity and mortality in a large number of women all across the world. Standard treatments, including surgery, chemotherapy, and radiation, generally have substantial toxicities and limitations in their ability to target tumor cells very selectively. More recently, in the last few decades, nanotechnology has offered a viable solution to address these challenges. Nanoparticles (NPs) of 1-100 nm in size appear to be a promising alternative for improving the delivery and therapeutic performance of breast cancer treatments (Mao et al., 2013).

Nanoparticle utilization in DDS offers several advantages, including more target-based approaches to cancer cells and thus greater preservation of healthy tissues. Such targeted delivery is enabled by the specific characteristics of nanoparticles of being small, with a large surface area, and a modifiable structure, which are ideal for surface modification to promote cellular uptake (Jain, 2008). These features have facilitated the employment of nanoparticles as drug carriers of different types of therapeutic agents, including classical chemotherapy drugs, nucleic acids, and even immune modulators (Ghosh et al., 2018).

The general kind of nanoparticles used in the therapy of breast cancer includes liposomes, dendrimers, solid-lipid nanoparticles, and gold nanoparticles, and have been widely exploited. For example, liposomes can be used to encapsulate hydrophobic drugs and to shield the drug from degradation, which results in prolonged circulation and an increase in uptake by the tumor (Allen & Cullis, 2013). Gold nanoparticles, however, have unique optical features, which may be used for both therapeutic and diagnostic applications, termed “theragnostic” (Huang et al., 2016).

In addition, MDR, a common cancer treatment obstacle, can also be infiltrated with nanoparticulate carrier systems for anticancer drugs. Encapsulation of chemotherapeutic agents into nanoparticles enables deeper penetration of the drug into the tumour cells and also decreases the induction of resistance mechanisms (Sengupta et al., 2005). Further, linking of target-specific ligands, such as antibodies or peptides, onto the surface of the nanoparticle system allows selective binding to receptors overexpressed in cancer cells, with consequent improved drug delivery specificity (Vivek et al., 2017).

Despite the remarkable progress made, there are still various challenges. Nanoparticle toxicity, stability, and immune reactivity considerations still need further investigation (Schroeder et al., 2011). Furthermore, the clinical facilitation of nanoparticle-mediated therapies encounters regulatory and manufacturing challenges that need to be overcome in order to be widely adopted (Jain et al., 2013).

In summary, the use of nanoparticles for breast cancer therapy presents potential opportunities to enhance the therapeutic efficacy and safety of available treatments. Further investigation in this direction is essential to maximize the benefit of nanotechnology in personalized cancer medicine.

1.2 Aim of the Project

Main objective of this study is to conduct some articles review and a critical evaluation of the use of nanoparticles in breast cancer therapy. Nanoparticles, with their distinct physicochemical characteristics, have emerged as a powerful candidate to tackle several of the traditional cancer therapy shortcomings (limited bioavailability, nontargeted toxicity, and systemic toxicity). This project will investigate different kind of nanoparticles that have been used in the treatment of breast cancer and how they work, their potential as a therapy for breast cancer, and the difficulties involved in using them in the clinic.

The primary purpose of the present study is to summarise and discuss the series of nanoparticles developed for breast cancer therapy. These carriers are liposomes, dendrimers, polymeric, gold and other type of nanoparticles, and so on. Similarly, these nanoparticles have their own properties which allow the sequestration and selectivity delivery of therapeutic cargoes, such as chemo drugs, gene and immune therapeutics. Examples of these include liposomes for the loading of hydrophobic drugs and stabilization of drug, and dendrimers for the loading of the drug with fine control on drug release and surface functionalization. Gold nanoparticles, meanwhile, have shown promise in drug delivery and a variety of in situ imaging applications, and may have potential utility in the context of theranostics. Understanding the strengths and weaknesses associated with different types of nanoparticles will likely make a significant contribution in clinical applications toward successful breast cancer therapyA major objective of this project is to summarize the group of nanoparticles used in treating breast cancer. These nanocarriers are liposomes, dendrimers, polymeric and gold nanoparticles etc. These nanoparticles all have distinct features that enable to capture and to specific deliver of therapeutic drugs, such as chemo drugs, gene therapies and immunotherapies. For example, liposomes are the most extensively used for hydrophobic drug loading and stabilization, whereas denderimers can better control drug release and surface functionalization. Gold

nanoparticles also have found successful applications in drug delivery and in situ imaging and may have the potential to be used as theranostics. Understanding the pros and cons of the different nanoparticles will definitely be an added value toward future clinical management of breast cancer.

A further important goal is to investigate how nanoparticles can improve drug uptake by breast cancer cells. Nanoparticles provide several ways to increase the drug delivery system, like. the EPR effect, leading to the preferential localization of the nanoparticles in tumors as a consequence of the pathological leaky vasculature of cancer tissues. Besides benefits mediated by the EPR effect, nanoparticles can be formulated with ligand decorations that bind to cancer cell-specific receptors, allowing for even more selective targeting of cancer cells and fewer side effects toward normal tissue. These mechanisms are essential for increasing the therapeutic index of cancer drugs and decreasing harmful side effects, a significant obstacle in conventional treatment.

Finally, the project will introduce the barriers and limitations in the clinical transformation of nanoparticle therapies, such as toxicity concerns, regulatory barriers, and the complexity of large-scale manufacturing. It will also discuss novel avenues of research to upgrade the specificity, safety, and effectiveness of nanoparticle-based therapies.

By conducting the review, the project will provide an extensive overview of nanoparticle applications in breast cancer treatment and grant new concepts in the modulation of these therapies to improve patient care.

1.3 Scope of the Project

In this review, the recent use of nanoparticles in the treatment of breast cancer will be discussed. In the study, different kinds of nanoparticles-drug delivery systems, including liposomes, dendrimers, polymeric nanoparticles, and gold nanoparticles, and their unique traits rendering them promising for targeted drug delivery, would also be discussed. The aim of the review will be to explain how NP can improve the bioavailability, targeting, and reduction of off-target effects for drug delivery, i.e, increasing efficiency of penetration in various biological activity barriers like the blood-brain barrier and tumor microenvironment.

The clinical implications of nanoparticle-based therapies will also be addressed by providing an overview of FDA-approved nanoparticle formulations and clinical trials in progress. The use of these nanoparticles in combination with other therapeutic methods - gene therapy, immunotherapy, and radiation therapy will be discussed by focusing on the possibilities for synergistic effects.

Furthermore, the range also focuses on limitations in nanoparticle-based cancer treatment like toxicity, immune response, stability, and mass production. This review will help for further improve the treatment procedure.

Finally, the purpose of this review is to inform about the potential of nanoparticles in the control of breast cancer in applications such as personalized therapy, and to allow for comprehensive knowledge of how nanoparticles can change breast cancer treatment as we know it.

Chapter 2

Methodology

This paper provides a review of nanoparticle utilization in breast cancer treatment. The information in the review comes from the pre-reviewed studies, journals, published articles, websites, and news. These study articles are from Nature Cell, MDPI, Frontiers, PubMed, PMC, and others. All the information is carefully recorded. Most of the review is focused on the types of nanoparticles and their action in the tumor cells versus normal cells. However, all the information is taken from different sources, but all the information on using nanoparticles in breast cancer treatment is jot down here. This study gives all the information on all kinds of nanoparticles used in the purpose of treatment of breast cancer.

Articles are chosen according to relevance, publication date (putting forward the most recent research studies), and relevance to a topic on NBDD of breast cancer. The topic on both preclinical and clinical studies of nanoparticle application will also be searched, and articles not within the scope and with a lack of data will be excluded.

Relevant information will be extracted from the selected articles, such as types of nanoparticles, drug delivery mechanisms, clinical applications, and the challenges posed by their use. This information has been summarized to identify research trends, research areas without any coverage of literature, and emerging technological trends.

A critical analysis of the potential and limitations of the nanoparticle-based therapies for breast cancer therapy will be conducted.

The review will aim to adopt a position between perspectives that can be justified with evidence from recent studies.

Chapter 3

Overview of Breast Cancer

3.1 Breast Cancer

Breast cancer arises in the breast tissues. It typically starts in the milk ducts or milk-producing glands. When it happens in milk ducts, it's called ductal cancer, and when it develops in the milk-producing gland, it's called lobular cancer. In breast cancer, breast cells grow uncontrollably and create a lump. These cells can spread to other parts of the body via the blood or lymph system (National Cancer Institute, 2022). Breast cancer may happen in both men and women, but in women, it is more common. Lump in breast, breast shape change, skin color change, nipple discharge, and pain in breast are the common signs of breast cancer. Sometimes, no symptoms are visible at first, but this makes the cancer dangerous and can lead to the third or fourth stage of cancer (Mayo Clinic, 2023). The risk factor depends on the family history, some genes like BRCA1 and BRCA2, early menstruation, late menopause, ageing, not using properly-sized undergarments, alcohol, and lack of physical activity. Breast cancer can be detected by a mammogram or a PET-CT scan.

If there is a family history of breast cancer, whether it is due to inherited gene mutations or other non-genetic factors, these can be added together to form a composite risk of breast cancer and should be examined along with the other factors. The survival rate is much higher when they are detected in the early stages because the tumor can be caught before it has become invasive through screening (mammography and ultrasound).

Treatment for breast cancer may involve surgery, chemotherapy, radiation therapy, and other targeted therapies. However, the efficacy of treatment can be affected or limited by drug resistance, general toxic effects on the body, and disease heterogeneity. Therefore, current research is aimed at identifying new personalized, more efficient therapies, such as the

therapeutic use of nanotechnology, the use of immunotherapy, and hormone-targeted therapy. Despite advances in early diagnosis and treatment, breast cancer is still one of the leading causes of death from cancer.

3.2 Types of Breast Cancer

Breast cancer is divided into several subtypes according to the source, molecular properties, and the degree of agressiveness of the cancer cells. The most common subtype is invasive ductal carcinoma (IDC) that starts in the milk ducts and extends into surrounding tissue, representing around 70-80% of the cases (Zhao99 et al., 2025). Invasive lobular carcinoma (ILC), the second most common subtype, arises in lobules that produce milk and is frequently more challenging to identify (Zhao et al., 2025). Non-invasive DCIS is usually limited to the ducts and is considered a possible precursor of invasive cancer (Priyadarshani, 2022).

Less common subtypes are the inflammatory breast cancer (IBC) in which lymphatic vessels are blocked, causing the breast to become red and swollen, and the triple-negative breast cancer (TNBC) that does not have estrogen, progesterone, and HER2 receptors, which is difficult to treat (Zhang et al., 2022). HER2-overexpressing breast cancer grows aggressively, but is sensitive to targeted agents such as trastuzumab (Priyadarshani, 2022). In general, breast cancer classification is a key factor in selecting the appropriate treatment and predicting patients' outcomes.

Stages of Breast Cancer:

Stages vary from 0 (non-invasive) to IV (the spreading of cancer to other organs). The stages are used to determined by the tumor's size and the rate of metastasis.

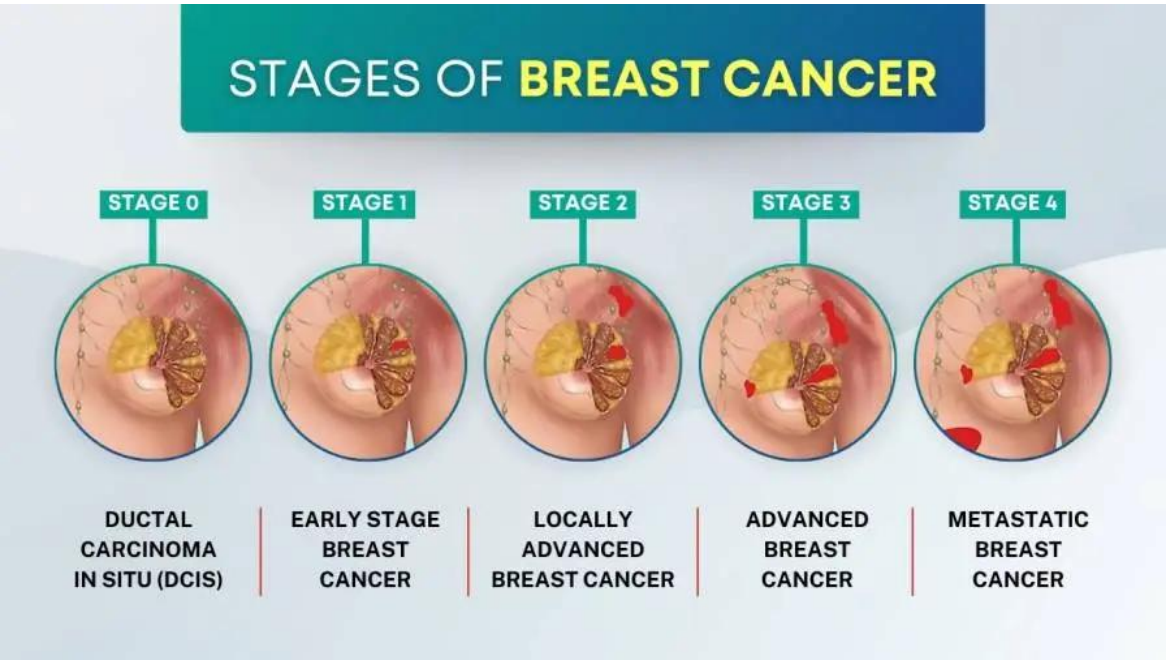

Figure 1: Stages of breast cancer, Kolhapur Cancer Centre, (2024, April 4). *The stages of breast*

Chapter 4

Nanoparticles in Breast Cancer

4.1 Basics of Nanoparticles

In the age of advancements in nanotechnology, nano-therapies are creating their own field commercially. This entered the clinical sector in the 1960s. Nanoparticles are tiny particles that are so tiny that they can not even able to be seen with a regular microscope, but need an electron microscope to observe. They are usually between 1-100 nanometers in size. If we consider a hair, which is about 80,000 nanometers wide, we can have an idea of how small nanoparticles are in size. The nanoparticles can be changed or designed according to the target-specific part of the body. The basic composition is a little bit complex(surface layer, shell layer, and core). These particles can be made of different materials like proteins, gold, silver, lipids, and polymers (National Cancer Institute, 2022).

In cancer treatment, nanoparticles began to be used in the 1990s with the first nanomedicine called Doxil, which is a liposomal formulation of doxurubicin and received clinical approval in 1995. Nanoparticles are used to carry out the drugs directly to the cancer cells which giving a proper site of action for the cancer drugs. This drug delivery system is known as a nanoparticle-based drug delivery system. It helps to treat the cancer more effectively in a short period. Normally, chemotherapy drugs go through the whole body via systemic circulation and affect both healthy and cancer cells, but if we pack the drug inside a nanoparticle, they will go to the tumor site directly without dissolving in the systemic circulation, then release the medicine only in the site where it’s needed to be released to damage cancer cells (Bhatia & Sailor, 2021).

Nanoparticles are designed as they can recognize and bind with the cancer cells. So this is called targeted therapy. Nanoparticle therapies are beneficial nowadays because of having

lower toxicity, improved treatment, and reduced drug wastage. The nanoparticles cross the blood-brain barrier and do not clear too quickly from the body, so that the half-life of the medication increases. They can be transfer a higher number of medicines without damaging the stability. They can be given in various routes, and which is better than how the microparticles carry the drug. Researchers are exploring the nanoparticles, their site of action, and their future career in the treatment of multiple cancers at different stages. In short, nanoparticles are offering a smarter and safer way to treat harmful diseases like cancer, so we need more attention to this treatment process.

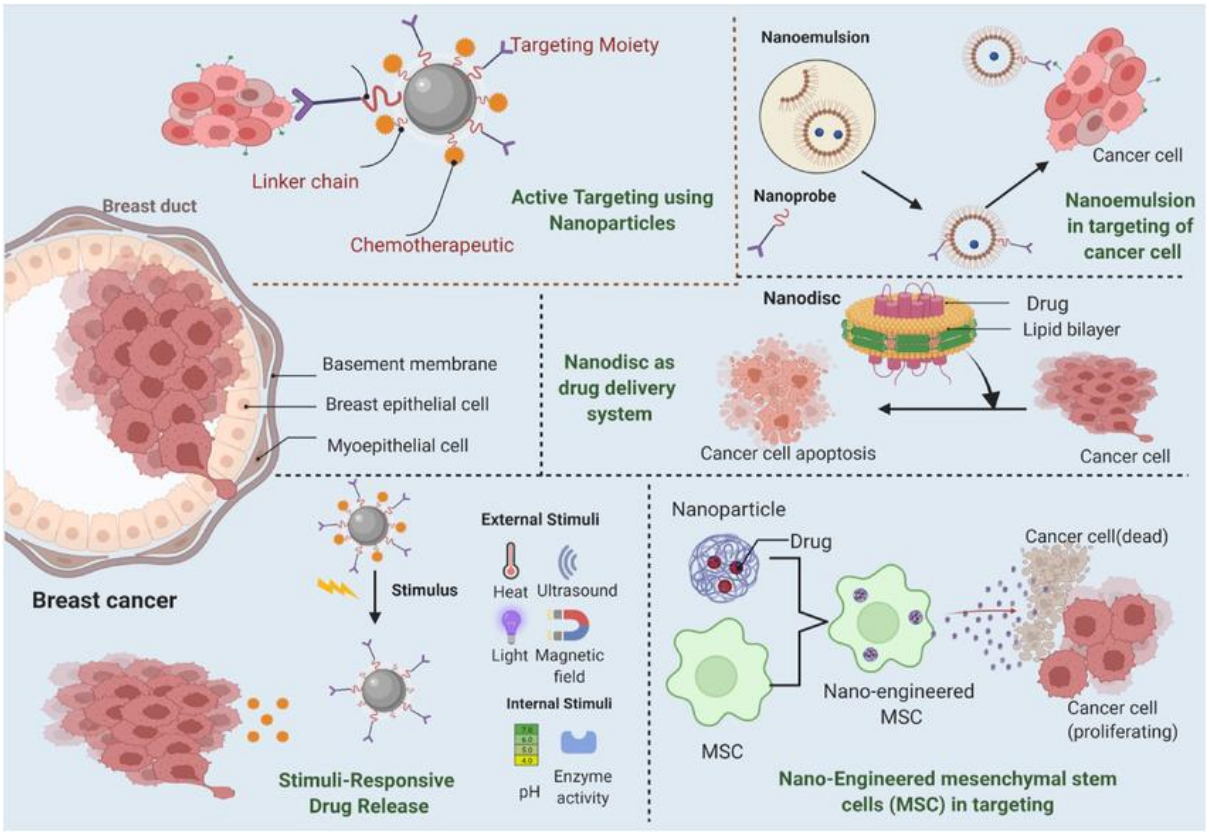

Figure 2: Mechanism of nanoparticles in breast cancer. ResearchGate. (2024). *Mechanisms of nanocarriers as a drug delivery system in breast cancer*. Retrieved from https://www.researchgate.net/figure/Mechanisms-of-nanocarriers-as-drug-delivery-system-in-breast-cancer_fig2_370919186

4.2 Types of Nanoparticles in Breast Cancer

Nanoparticles are of different kinds, having different characteristics based on their application as drug carriers and therapeutic agents. Liposomes are lipid nanoparticles that can easily contain both hydrophobic and hydrophilic drugs, resulting in improved stability and bioavailability. Polymeric nanoparticles, which are most commonly synthesized from biodegradable polymers such as PLGA, facilitate sustained release and low toxicity of the drug. Dendrimers are hyperbranched, nano-sized polymers that can govern drug delivery and functionalization with excellent precision. Gold nanoparticles are biocompatible and have distinct optical properties, which have led to their application in theranostics. Solid lipid nanoparticles (SLNs) are formulations of lipophilic drugs in a lipid deposition system for improved stability and variable release patterns.

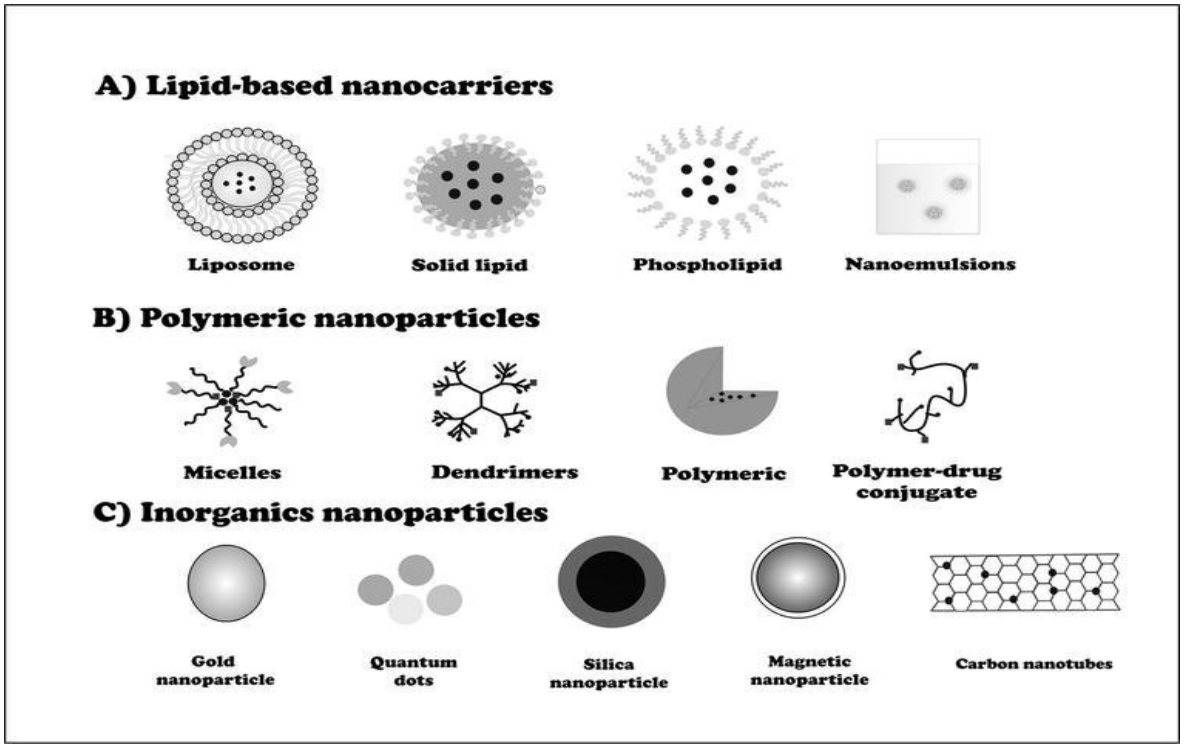

Figure 3: Types of nanoparticles. (ScienceDirect. (n.d.). *Engineered nanoparticles*. In *ScienceDirect*. https://www.sciencedirect.com/topics/engineering/engineered-nanoparticles)

Nanoparticles in breast cancer therapy and diagnostics consist of:

Liposomes: Nanoparticles Made from Fats. These fatty nanoparticles target cancer cells by delivering drugs or genes to them with great precision, reducing the side effects.

Polymeric Nanoparticles: They are composed of most likely biodegradable polymers and transport drugs or genes, and possibly can be targeted to harmful cells to minimize damage to healthy tissue.

Gold Nanoparticles: For imaging, drug delivery, and photothermal therapy, gold nanoparticles can target cancer cells with deadly precision.

Magnetic NPs: These are utilized in MRI and as carriers for drug delivery, offering controlled release of drugs.

Carbon nanotubes: Best at carrying drugs directly to cancer cells, they even appear to have potential for imaging and photothermal therapy.

Chapter 5

Available Nanoparticles to treat breast cancer

5.1 Lipid-Based Nanoparticles in Breast Cancer Therapy

Lipid-based nanoparticles are small fat-based carriers which is useful in the treatment of cancer. These LNPs are safer in the body. These drugs are both water-loving and fat-loving at the surface, if they can be changed. This characteristic makes the treatment more fruitful because it helps to dissolve the drug more easily and store it long-term in the body, also easily reaches the right place, like breast cancer cells, more effectively (Talluri et al., 2016).

Liposomes: Liposome spherical vesicles with lipid bilayers that accumulate in the tumors due to enhanced permeability and retention (EPR) effect caused by the fenestrated tumor microvasculature and limited lymphatic drainage (Gabizon et al., 2003). Drugs like doxorubicin modify the biodistribution, increasing drug accumulation in tumors without stopping therapeutic efficacy (Allen & Cullis, 2004; Barenholz, 2012). In breast cancer models, liposomal doxorubicin, either alone or in combination with aprepitant, shows increased tumor suppression and reduced oxidative stress in cardiac and liver tissues (Al-Azawi et al., 2024).

Solid Lipid Nanoparticles (SLNs): Solid lipid nanoparticles are tiny particles that are made of solid fats, which can carry medicines inside them. These fats are solid at room temperature(25 degrees Celsius) and body temperature, which helps the medicine to release slowly in the body over time.SLNs are very small—usually less than 1 micrometer (like 100–1000 nanometers)—and are covered by a layer that keeps them stable (Priyadarshani, 2022). SLNs are more stable than liposomes. SLNs are used in breast cancer treatment. They can carry

chemotherapy drugs like doxorubicin, temozolomide, and tamoxifen directly to the tumor, helping to kill cancer cells more effectively while causing fewer side effects (Nanomaterials MDPI, 2019; PMC, 2023).

5.2 Polymeric Nanoparticles

Polymeric nanoparticles are very small carriers, which are between 10–1000 nanometers in size and made from safe, natural, or synthetic materials (like PLGA or chitosan). They are used to deliver medicine directly to specific parts of the body. In tumors, they are more effective.

PLGA (Poly lactic-co-glycolic acid):

PLGA (poly lactic-co-glycolic acid) nanoparticles are biodegradable carriers that can deliver chemotherapy drugs to the tumor directly. They improve the stability, reduce side effects, and allow the controlled release of the drugs. PEG-coated PLGA nanoparticles release drugs more effectively in tumor environments, which reduces the early leakage of the drug into the bloodstream.

PEGylation (using PEG):

PEGylation involves coating of nanoparticles with the polyethylene glycol (PEG). This process helps them circulate longer in the body and avoid immune detection. As a result, it improves drug delivery to breast tumors (Zhao et al., 2025). PEGylated nanoparticles that carry siRNA or chemotherapy drugs like paclitaxel and disulfiram can overcome resistance and target aggressive breast cancers (Suliman et al., 2025).

5.3 Metallic or Inorganic Nanoparticles

Metallic nanoparticles are tiny particles made up of metals like gold, silver, or iron. They are usually between 1–100 nanometers in size. As they are super small, they can easily enter the tumor cells and kill the cancer cells.

Gold Nanoparticles (AuNPs):

Gold NPs are engineered in distinct shapes to effectively absorb near IR and transform it to localized heat for cancer cell destruction. These have been extensively applied in photothermal therapy (PTT) for breast tumors. They can be engineered to transport anticancer therapies and directly administer them to the tissues. Gold nanoparticles are also employed in cancer imaging and diagnosis.

Silver nanoparticles (AgNPs):

Silver nanoparticles (AgNPs) display anticancer activity because they are capable of generating ROS leading to oxidative stress in cancer cells. These ROSs cause cellular damage to DNA and mitochondria, which result in apoptosis. Anticancer activities of AgNPs have been described in some previous reports, and it has been found that they can retard tumorigenesis by affecting cellular mechanistic pathways and apoptotic induction in several breast cancer cell types, including MCF-7. Because of their biocompatible, localizable property, and their sensitizer of chemotherapy, AgNPs may have a prospect in cancer therapy.

Iron oxide nanoparticles:

These nanoparticles are used in magnetic hyperthermia in cancer treatment. IONPs are injected into the tumor site where the cancer is located. Magnetic fields are used to heat(around 42–45°C) the nanoparticles inside tumors, causing cancer. They are also used as MRI contrast agents to improve imaging and early detection of breast tumors by scanning in the MRI machine. IONPs can also be loaded with anticancer drugs like doxorubicin. IOPNs are coated

with targeting agents like antibodies or ligands, which guide the drug to breast cancer cells, as a result cell dies.

Carbon Nanotubes (CNTs):

Carbon Nanotubes carry anticancer drugs straight to the breast cancer tumor cells and kill the cancer cells with the less side effects to the normal cells than usual chemotherapy does to the normal cells.CNTs absorb near IR and turn into heat, then the temperature of the tumor rises as a result, and the cancer cells are destroyed without any traditional surgery. They can deliver some genetic material which are responsible for cancer cell death, like siRNA, to turn off the growth of harmful genes.

Nanoparticles in Drug Delivery (2013–2023)

Nanoparticle	Composition and Structure	Drug Delivery System	References
Liposomes	Phospholipid bilayer vesicles	Encapsulate hydrophilic and lipophilic drugs; controlled release via fusion with cell membranes	Allen, T. M., & Cullis, P. R. (2013).
Polymeric Nanoparticles	Biodegradable polymers (e.g., PLGA, PEG)	Sustained release through diffusion; surface modification for targeting via ligands	Ganta, S., & Devalapally, H. (2017).
Solid Lipid Nanoparticles	Solid lipid core stabilized by surfactants	Encapsulate lipophilic drugs; controlled release via lipid matrix degradation	Müller, R. H., & Keck, C. M. (2016).

Dendrimers	Branched, tree-like macromolecules	High drug loading; controlled release via surface functionalization	Dendukuri, D., & Hatton, T. A. (2007).
Magnetic Nanoparticles	Iron oxide or iron-platinum cores	Targeted delivery via external magnetic fields; controlled release via hyperthermia	Pankhurst, Q. A., Connolly, J., Jones, S. K., & Dobson, J. (2003).
Mesoporous Silica Nanoparticles	Silica with ordered pores	High surface area for drug loading; controlled release via pore size and surface modification	Zhang, Y., & Zhu, Y. (2017).
Quantum Dots	Semiconductor nanocrystals	Fluorescent properties for imaging; potential for drug delivery via surface conjugation	Alivisatos, A. P. (2004)
Carbon Nanotubes	Cylindrical carbon molecules	High drug loading; controlled release via surface functionalization	Liu, Z., Robinson, J. T., & Sun, X. (2013).

Chapter 6

Specific approved drugs & In clinical trial drugs

Nanoparticle-based therapy has become a revolutionary treatment strategy for breast cancer in that it delivers drugs more efficiently, prevents systemic toxicity, and improves therapeutic outcomes. Many nanoparticle formats have been granted regulatory approval and many clinical trials are in progress for further examination of their abilities.

FDA-Approved Nanoparticle-Based Therapies for Breast Cancer

Nanoparticles/Drugs	Description	Current Status	Reference
Abraxane® (Nab-paclitaxel)	Albumin-bound paclitaxel formulation; enhances solubility and targeted drug delivery.	Approved for metastatic breast cancer, lung cancer.	(National Cancer Institute, 2024)
Doxil® (Liposomal Doxorubicin)	Liposomal formulation of doxorubicin for reduced cardiotoxicity and targeted delivery.	Approved for breast cancer (off-label), ovarian cancer.	(Cancer Science, n.d.)
Enhertu® (Fam-trastuzumab deruxtecan	Antibody-drug conjugate combining trastuzumab with a topoisomerase I inhibitor.	Approved for HER2-positive breast cancer.	(National Cancer Institute, 2024)

Ongoing clinical trial of nanoparticle-based therapies for Breast Cancer

Nanoparticles/Drugs	Description	Current Status	Reference
Polymeric Nanoparticles for Targeted Delivery	Nanoparticles engineered for controlled drug release in response to tumor stimuli.	Investigational stage in targeted breast cancer therapies.	(Biointerface Research, 2020)
Nanoparticle-Based Gene Therapy	Nanoparticles are used for the efficient delivery of genetic material to tumor cells.	Preclinical and clinical trials are underway.	(ScienceDirect, 2019)
Combination Nano therapy	Nanoparticles are used in combination with chemotherapy, immunotherapy, or photothermal therapy.	Ongoing trials evaluating synergistic effects.	(Journal of Nanobiotechnology, 2020)

Chapter 7

Limitations and Future Perspectives of the study

7.1 Limitations of using nanoparticles in Breast cancer

The articles that are selected for this review might be biased due to any meta-analysis. Geographical change may vary the action of the treatment. Other factors also have a huge impact on breast cancer treatment.

Whether nanoparticles are toxic is one of the most critical issues in the field of nanotechnology for breast cancer therapy. While nanoparticles are engineered to deliver drugs directly to cancer cells, they can also bind to other tissues in the body and result in side effects. For instance, targeting nanoparticles to organs such as the liver, kidneys, and spleen may cause undesirable consequences in terms of organ injury and the immune system reaction (Iravani et al., 2014). Biocompatibility of NPs is related to size, surface charge, and material composition, which must be designed to reduce toxicity. Chronic health problems may also arise due to chronic residence of nanoparticles in the body, leading to complications in their clinical applications.

The regulatory route of nanoparticle therapeutics is complicated due to the use of new materials and action mechanisms that are not yet fully understood. Regulators like FDA and EMA need to review the safety and effectiveness of nanoparticles; however, the absence of standard criteria for nano-material test drives creates a grey area in regulation (Jain, 2014).

In addition, the safety of repeat dosing of nanoparticles in humans is a critical issue. Considering the potential for cumulative toxicities, as well as off-target immune responses or unanticipated adverse effects, these treatments should be vigorously assessed in preclinical and clinical studies for safety.

7.2 Future perspective

With the progression of precision medicine, the nanoparticle-based therapy will be developed in based on genetically or molecularly personalized patients. Bespoke therapies could entail the development of nanoparticles directly targeting the genetic mutations or overexpressed receptors found only in a patient's breast cancer (Cheng et al., 2020). For instance, nanoparticles could be designed to recognize HER2-positive breast cancer cells and carry drugs or genes to tumor cells, leaving non-transformed cells alone and mitigate side effects while enhancing treatment. These personalized methods will can be used not only for monitoring but to adjust therapies in real-time, thereby improving therapeutic response.

The next generation of nanoparticle-based therapeutics for treating breast cancer may be a combination therapy in which the nanoparticles are used to co-deliver multiple therapeutic agents. These could include chemotherapy, immunotherapy, gene therapy, and may be photothermal therapy (Ma et al., 2019). For example, nanoparticles may be ideal for encapsulating two or more drugs or biomolecules and releasing them at different rates. Such strategies can be used to address problems such as drug resistance, a common obstacle in cancer therapy, in order to increase the overall efficacy.

One of the primary causes of chemotherapy failure in metastatic breast cancer is still multidrug resistance, which is frequently brought on by P-glycoprotein (P-gp) efflux pumps. By delivering medications intracellularly through endocytosis and avoiding efflux routes, nanoparticles can avoid these pumps. Additionally, nanoparticles can co-deliver gene-silencing agents such as small interfering RNA (siRNA) to suppress the expression of resistance-related genes, restoring drug sensitivity (Wang et al., 2021).

Chapter 8

Conclusion

Breast cancer is the most prevalent and avoidable cancer in women around the world. It can be cut out of the body for good if it’s caught in the early stage. Conventional treatments such as surgery, radiation, and chemotherapy have improved the way we treat cancer, but the recent advancements in nanoparticles have transformed treatment for many patients, as the treatment tends to be more accurate, targeted, and causes fewer side effects. This trend has led to the increasing focus on the use of nanotechnologies for cancer therapy. The physical and chemical characteristics of nanoparticles are so special. Because they are very small, nanoparticles have many benefits, as they can carry the desired drug. Nanoparticles possess active and passive targeting features. These characteristics enable better local tumor concentration. As in the treatment of breast cancer, they can act as a drug carrier for chemotherapy, for drugs, including doxorubicin, paclitaxel, etc, preserving the problem of multi-drug resistance in the sense of nanoparticles.

The application of nanotechnology to enhance the diagnostic and therapeutic (visual diagnosis, demarcation, and ablation) capacities of BC has also received much interest, as evidenced by the increasing number of recent studies utilizing NPs for BC management. Different types of NPs are discussed, such as lipid NPs, polymer NPs, inorganic ones (magnetic, gold, and mesoporous silica NPs), and carbon nanotubes. This article is part of the themed issue 'Nanoscience research in food science'.The use of such nanocarriers in the treatment of breast cancer offers promise to circumvent numerous drawbacks of conventional treatment, including poor bioavailability, lack of selectivity, and multiple drug resistance (Allen & Cullis, 2013; Pankhurst et al., 2003).

Nanoparticles have varied and efficient drug delivery mechanisms. Lipid nanoparticles, including liposomes, have been proposed for making drugs (including arsenic) stable in solution, aiding controlled drug release and selective drug targeting in cancer tissues. Polymer particles, in particular biodegradable particles such as PLGA, allow for controlled drug release that can be modulated to obtain therapeutic success. Further utilizing magnetic nanoparticles could allow the application of targeted drug delivery through an external magnetic field, reducing systemic toxicity and maximizing the drug at the tumor (Müller & Keck, 2016). Mesoporous silica nanoparticles provide large surface area and desirable pore size distribution that collect the potential of controlled release, drug loading: and improved therapeutic efficacy (Zhang & Zhu, 2017). Gold nanoparticles have also demonstrated theranostic potential, as they are capable of being used in tandem as both therapeutic and diagnostic agents, and have thus risen the ranks as a pivotal theranostic option (Huang et al., 2016).

The potential of nanoparticle therapies is not to be underestimated, though. In summary, DX-NPs encapsulated in DX carrier demonstrated significant targeting of DX, improving the bioavailability of PWS drug, and the possibility of delivering multiple therapeutic drugs--a step towards personalized therapy for breast cancer patients. Nanoparticle systems are developing, but few major problems remain to be solved: improving the stability of nanoparticles and reducing the immunogenicity and functionalizing them for a greater specificity to cancer cells (Kwon & Okano, 2012).

Finally, the improvement of nanoparticles used in breast cancer therapy is a fascinating page in the history of cancer treatment. Nanoparticles provide a hope for the next era to pre-existing adaptive, effective, and safer breast cancer therapy with the longest shelf life (future) of ever 70 years! Oncologic nanomedicine's future looks bright, and further developments towards obtaining optimal nanotherapy may support more successful clinical practice.

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