

Biomedical Nano Technology in Cancers Cells

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Abstract—Cancer is a major global health challenge characterized by uncontrolled cell proliferation, resistance to apoptosis, local tissue invasion, and metastasis. Conventional cancer therapies, including surgery, radiotherapy, and chemotherapy, have significantly improved patient outcomes; however, their lack of specificity can cause damage to healthy tissues and various adverse effects. Biomedical nanotechnology has emerged as a promising approach for improving cancer diagnosis and therapy through the development of nanoscale drug delivery systems. Nano particles possess unique physicochemical properties, including a high surface area, tunable surface characteristics, improved drug solubility, and the ability to facilitate passive or active tumor targeting. This review provides an overview of cancer, including its pathophysiology, genetic mechanism, hallmarks, major types such as breast, lung, liver, blood cancer. The principles and applications of biomedical nanotechnology in targeted drug delivery, cancer detection, imaging, gene therapy, photothermal therapy, and magnetic hyperthermia are discussed.

Index Terms—Cancer, Biomedical Nanotechnology, Nanoparticles, Targeted Drug Delivery

I. INTRODUCTION:

Cancers can be cured by means of both conventional tonic approaches, i.e., surgery, radiation therapy and chemotherapy, and nonconventional or complementary therapeutic methods, including hormone therapy, immunotherapy, nano therapy, etc¹ These well-established therapeutic interventions specifically target the tumors and either inhibit or slow down the growth rate of cells, but incompetent to completely provide protection. Largely distress the normal cells, tissues, and organs. Selecting the best cancer therapy approach depends on various factors, such as the type of malignancies, growth stages, age, management frequencies, dosage of medicines, and healthiness of patients.²

According to the World Health Organization, cancer is the second leading cause of death globally and is responsible for about 10 million deaths per year. Cancer is the most prevalent life-threatening disease which is spreading because of the lifestyle followed nowadays.³

II. KEY CONCEPT & MECHANISM:

Normal vs. cancerous cell division in healthy tissue, damaged or old cells are routinely or destroyed via programmed cell death (apoptosis). Cancer cells override these regulatory signals, continuing to divide indefinitely.⁴

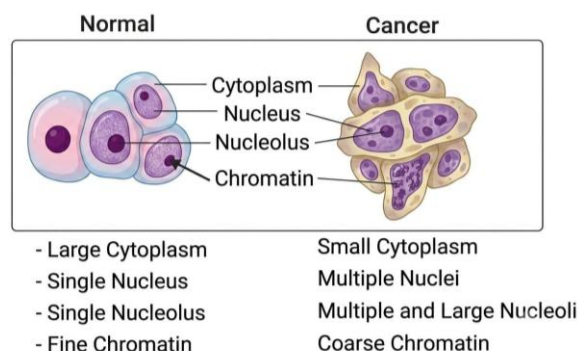


Figure No.1: Normal and Cancer Cell structure

III. PATHOPHYSIOLOGY OF CANCER:

Cancer development is a multi-step genetic and cellular process driven by accumulated DNA mutations that disrupt normal cellular regulation, leading to uncontrolled proliferation, tissue invasion, and metastasis.

1.Carcinogenesis Phase Model

Carcinogenesis involves through three distinct stages: Initiation: Exposure to a carcinogen (chemical, physical, or biological) causes irreversible DNA damage or mutation in a single somatic cell.

Promotion:

Unmutated or weakly mutated cells are exposed to growth factors, hormones, or chronic inflammation, stimulating selective expansion of the initiated cell into a pre-neoplastic lesion.

Progression:

Accumulation of additional genetic driver mutations increases genomic instability, converting the benign lesion into an invasive neoplastic tumor.⁵

2.Genetic Drivers of Cancer

Cancer pathophysiology centers on mutation in three primary categories of regulatory genes:

Proto- oncogenes \ right arrow oncogenes:

Gain of function mutation in normal growth promoting genes lead to constitutively active proteins that continuously signal of cell division without external growth factors.⁶

TP53 (p53): The "guardian of the genome," which halts the cell cycle at G₁/S for DNA repair or triggers apoptosis.

RB1 (Retinoblastoma):

Regulates the E2F transcription factor family to control the entry into the S phase.

3. The Hallmarks of Cancer

Modern oncology categorizes cellular alterations into core capabilities acquired during tumor development Hallmark Mechanism Pathophysiological Process.⁷

4. Local Invasion and the Metastatic Cascade:

Epithelial-to-Mesenchymal Transition (EMT): Tumor cells downregulate cell-adhesion molecules (E-cadherin) and gain migratory, mesenchymal phenotypes.

Extracellular Matrix (ECM) Degradation:

Tumor cells secrete matrix metalloproteinases (MMPs) to digest the basement membrane and stromal matrix.

Intravasation: Cells enter nearby blood or lymphatic capillaries.⁸

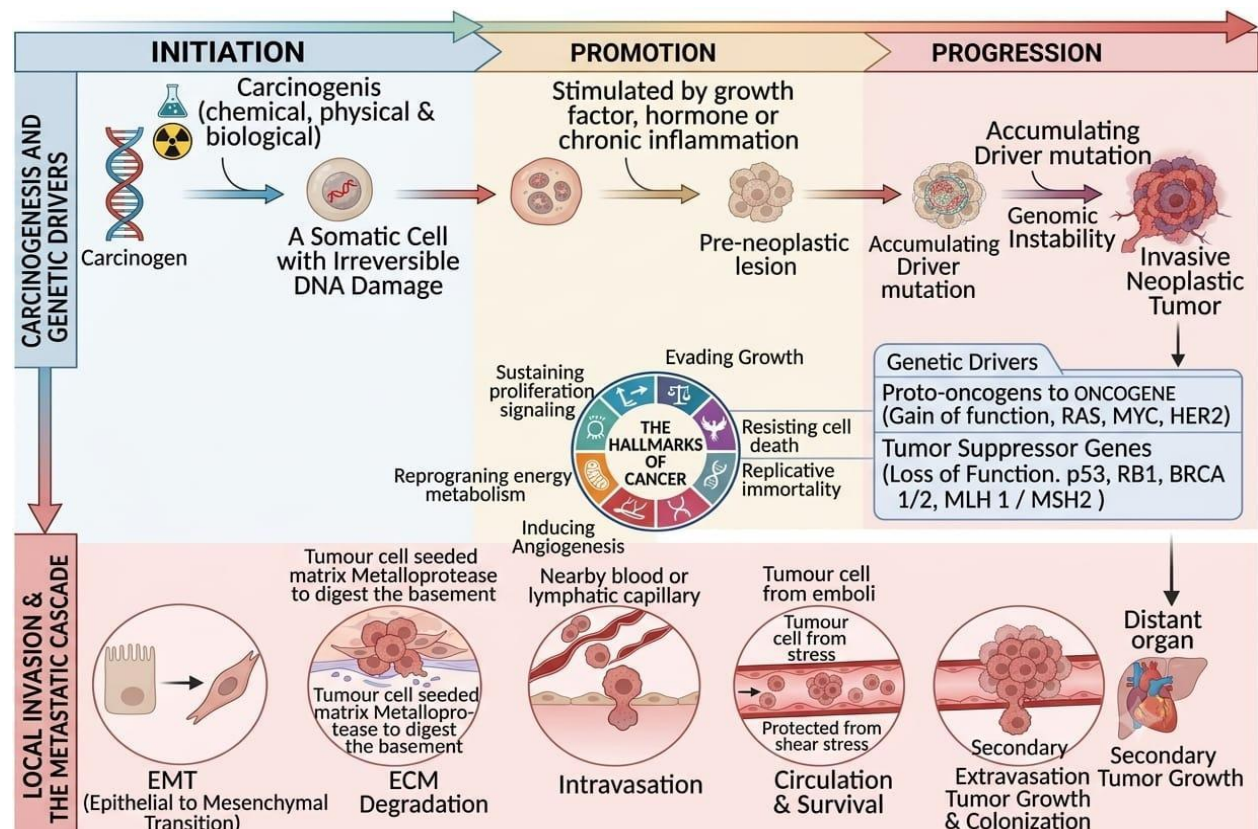


Figure No.2: Pathophysiology of caners cell

IV. VARIOUS TYPES OF CANCER:

Cancer Category	Tissue of Origin	Primary Biological Function/Characteristics	Example
Carcinoma (~80-90% of all cancers)	Epithelial tissue (cells that line internal organs, body cavities, glands, and the outer skin surface)	Forms solid tumors. Arises from cells exposed to environmental factors, chronic inflammation, or glandular secretion demands.	Breast cancer Prostate cancer Colorectal cancer
Sarcoma (~1% of adult cancers)	Mesenchymal/Connective & Supportive tissue.	Forms solid tumors in deep structural tissues. Often presents as a painless mass or bone pain.	Bone cancer. Cartilage cancer. Bone/soft tissue cancer Skeletal muscle cancer Fat tissue cancer
Leukemias	Hematopoietic (blood-forming) tissue in the bone marrow	Liquid cancer." Overproduction of abnormal, immature white blood cells that crowd out normal RBCs, WBCs, and platelets, causing anemia, infection, and bleeding.	Pediatric cancer
Germ Cell & Blastemic Cancers	Germ cells (sperm/egg precursors) or embryonic blastema. Arises from pluripotent cells that fail to differentiate properly.	Blastomas are predominantly pediatric cancers.	Seminoma ⁹

1)Breast cancer

Breast cancer is the most commonly diagnosed cancer in women and is the second leading cause of cancer related deaths among women. Carotenoids are proposed to have similar mechanism of action in breast and prostate cancer.

Symptoms:

- Changes in Breast Shape or Size: Unexplained swelling, distortion, or asymmetry.
- Skin Changes: Dimpling, puckering, redness, or skin texture changes resembling an orange peel.
- Nipple Alterations: Inverted or turned-in nipple, scaling, redness, or pain around the nipple area.
- Nipple Discharge: Any unusual discharge other than breast milk, particularly if clear or bloody.

Causes

- Family or Personal History: A family history of breast/ovarian cancer or a personal history of dense breast tissue/benign conditions.
- Hormonal Factors: Early menstruation (before age 12), late menopause (after age 55), or long-term hormone replacement therapy (HRT).
- Lifestyle Factors: Obesity, lack of physical activity, alcohol consumption, and smoking.¹⁰

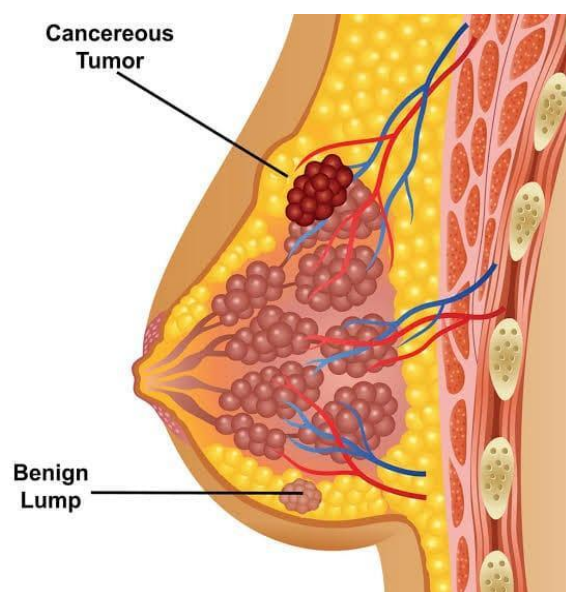


Figure No.03: Breast Cancer

2)Lung cancer

Lung cancer is the second most commonly diagnosed cancer and is the most common cancer-related deaths among both men and women. Cigarette smoking is the primary cause of lung cancer. It closely associated with less healthful diets including lower consumption of fruits and vegetables.

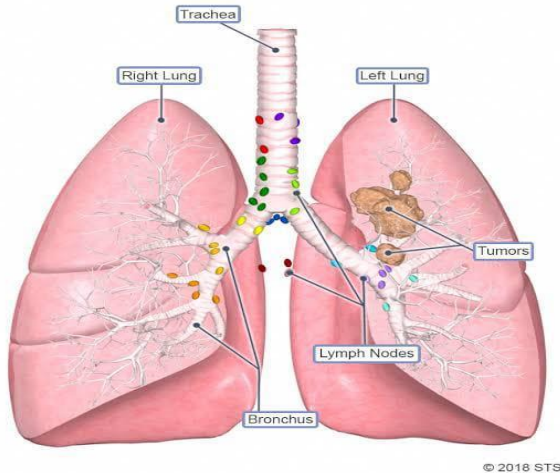


Figure No.04: Lung Cancer

Symptoms:

- **Persistent Cough:** A chronic cough that lasts for weeks, worsens over time, or changes in character.
- **Coughing Up Blood:** Even small amounts of blood or rust-colored phlegm.

- **Shortness of Breath & Wheezing:** Difficulty breathing or a high-pitched whistling sound during inhalation.
- **Chest Pain:** Aching in the chest, shoulder, or upper back that worsens with deep breathing or coughing.

Causes:

- **Tobacco Smoke:** Cigarette smoking is the leading cause (responsible for 80–90% of cases), along with exposure to secondhand smoke.
- **Air Pollution:** Prolonged exposure to heavy particulate matter and environmental pollutants.
- **Family History:** A family history of lung cancer.
- **Genetics:** Inherited genetics factors
- **Previous Lung Diseases:** Scarring from conditions like COPD, pulmonary fibrosis, or prior chest radiation.¹¹

3) Liver cancer: Liver cancer can describe the extent of cancer in the body. Knowing the stage of liver cancer helps the doctor plan the best treatment.

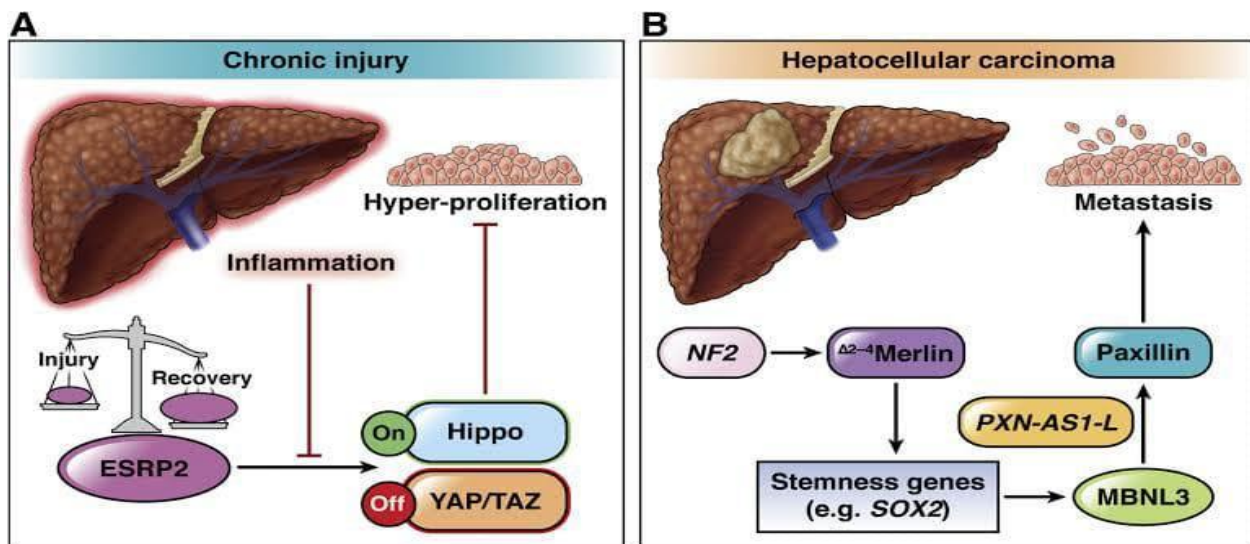


Figure No. 5 Liver Cancer

Symptoms:

- **Abdominal Pain & Swelling:** Pain or tenderness in the upper right side of the belly, near the right shoulder blade, or fluid swelling in the abdomen (ascites).
- **Jaundice:** Yellowing of the skin and whites of the eyes, often with dark urine and pale or chalky stools.
- **Unintended Weight Loss & Appetite Loss:** Losing weight rapidly without trying, or feeling full after eating very little.

- **Digestive Issues:** Persistent nausea, vomiting, or bloating.

Causes:

- **Most liver cancers are linked to long-term liver damage or scarring (cirrhosis).**
- **Chronic Hepatitis Infections:** Long-term Hepatitis B or Hepatitis C virus infection is the primary cause worldwide.

- Non-Alcoholic Fatty Liver Disease (NAFLD/NASH): Fat buildup in the liver, heavily linked to obesity and type 2 diabetes.
- Heavy Alcohol & Tobacco Use: Long-term excess drinking damages liver cells, while smoking increases cancer risk.¹²

4) Blood cancer:

Cancers that affect the blood, lymphatic system & bone marrow are known as blood cancer. Leukemia, Lymphoma and Myeloma are main three types of blood cancer.

Leukemia and myeloma start from bone marrow where Blood is produced. Lymphoma starts from lymphatic system. Lymphoma is the most commonly occurring blood cancer.

Symptoms:

- Fatigue & Pale Skin: Severe tiredness, weakness, and paleness due to a shortage of red blood cells (anemia).
- Frequent Infections: Recurrent fevers, chills, or persistent infections caused by a lack of healthy white blood cells.
- Easy Bruising & Bleeding: Frequent nosebleeds, bleeding gums, heavy periods, or tiny red skin spots (petechiae) due to low platelet count.

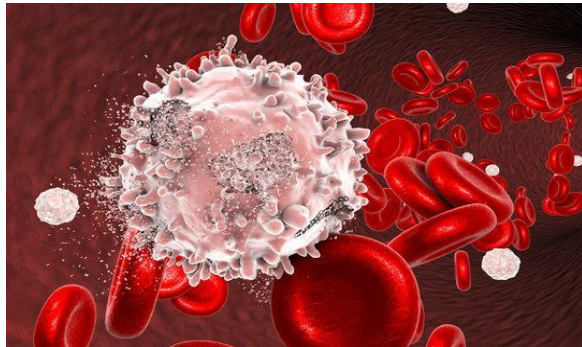


Figure No. 06: Blood Cancer

Causes:

- Prior Cancer Treatment: Past chemotherapy or radiation therapy for other cancers.
- Genetic Disorders: Conditions such as Down syndrome, Fanconi anemia, or Li-Fraumeni syndrome.
- Radiation Exposure: Exposure to high levels of ionizing radiation.¹³

V. BIOMEDICAL NANOTECHNOLOGY

Biomedical Nanotechnology:

Biomedical describes the application of biological and natural science principles to medicine and healthcare. It bridges the gap between basic biology and clinical practice to understand, diagnose, prevent, and treat human diseases.¹⁴

Nanotechnology is a multidisciplinary scientific field that deals with the formulation, preparation, characterization and application of structures, devices and systems at nanometric scale. Biomedical nanotechnology is dedicated to exploring nanoscience and nanotechnology for health wellness, with the ultimate goal of personalized health management. Reports released by health agencies have confirmed the significant role technologies play in disease monitoring, treatment, and progression management.

The tunable performance of nano-systems, investigated for biomedical research, is advantageous for the design and development of therapies that consider patient profiles i.e., personalized health management. Besides salient features of nano-assisted approaches, the introduction of numerical approaches i.e., artificial intelligence (AI), involving deep & machine learning, and bioinformatics has emerged as a very useful tool in understanding predictions and trends.¹⁵

VI. APPLICATION OF BIOMEDICAL NANOTECHNOLOGY

1.Targeted Drug Delivery

- Precise Targeting: Nanocarriers deliver drugs directly to diseased cells (e.g., tumors), reducing damage to healthy tissue.
- Gene & Vaccine Delivery: Lipid nanoparticles encapsulate fragile cargo, making technologies like mRNA vaccines possible.¹⁶

2. Diagnostics & Imaging

- Early Detection: Biosensors detect disease biomarkers in tiny amounts (blood, saliva) for fast point-of-care diagnostic.

3. Antimicrobials & Wound Care

- Infection Control: Silver and metal nanoparticles naturally kill bacteria, preventing infections in

wound dressings and surgical equipment without overusing antibiotic.¹⁷

4. Point-of-Care Biosensors and Diagnostics

- Utilizing functionalized gold nanoparticles or carbon nanotubes on lateral flow strips to detect low concentrations of biomarkers.
- Enables rapid testing for pathogens, cardiac markers, and glucose levels within minutes outside a laboratory setting.¹⁸

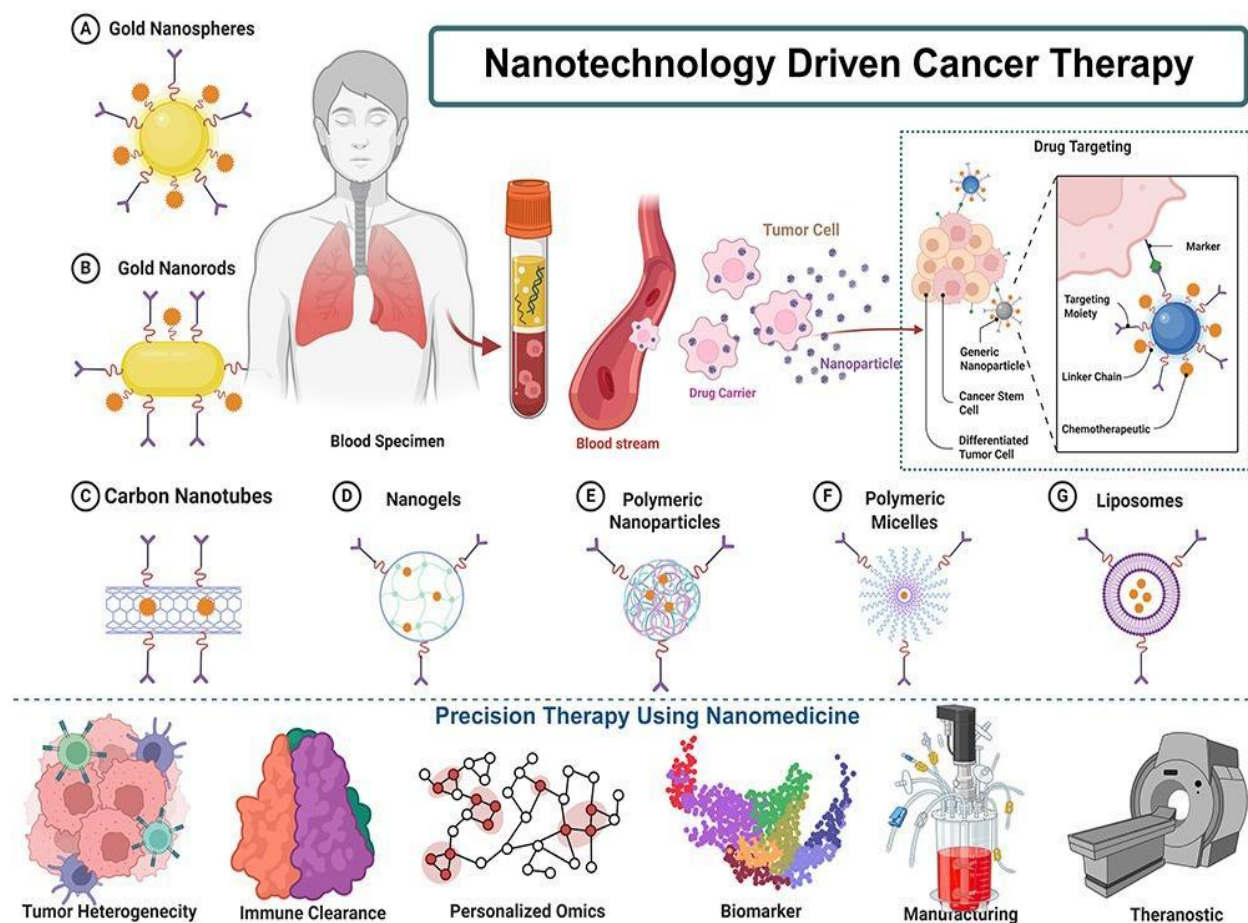
5. Photothermal and Photodynamic Therapy

- Injecting metallic nanoparticles (e.g., gold nanorods) that absorb near-infrared light and convert it into localized heat or reactive oxygen species.
- Thermally ablates surrounding solid tumor cells without requiring invasive surgery.¹⁹

VII. HOW BIONANOTECHNOLOGY OCCUR ON THE CANCER CELLS:

Nanoparticles as nano-carriers can increase solubility, stability, specificity, multimodality, and efficacy, while reduce toxic side effects and improve upon the non-specificity of conventionally delivered cancer treatments.²⁰

- Gold Nanospheres:** Used in cancer imaging and photothermal therapy to destroy cancer cells using heat.
- Gold Nanorods:** Convert light into heat to damage tumour cells.
- Carbon Nanotubes:** Used as drug carriers and investigated for cancer detection and treatment.
- Nanogels:** Carry drugs and release them in a controlled manner.
- Polymeric Nanoparticles:** Deliver anticancer drugs to tumour tissues.
- Polymeric Micelles:** Improve the solubility and delivery of poorly water-soluble anticancer drugs.
- Liposomes:** Fat-based vesicles that carry anticancer drugs and alter their distribution in the body.²¹



VIII. CASE STUDY OF BIOMEDICAL NANOTECHNOLOGY IN CANCER THERAPY:

1) Inhalable biometric polymeric nanoparticles for targeted chemotherapy in non-small cell lung cancer:

1. Background & Clinical Rationale:

Non-Small Cell Lung Cancer (NSCLC) remains a leading cause of cancer mortality worldwide, often limited by late-stage diagnosis and poor response to conventional systemic intravenous chemotherapy. Systemic delivery of therapeutic agents like Paclitaxel (PTX) or Cisplatin frequently results in low drug accumulation within deep pulmonary lesions, alongside severe off-target toxicities (such as nephrotoxicity and peripheral neuropathy). This case study evaluates an inhaled biomimetic polymeric nanoparticle delivery system designed to overcome physiological lung barriers and enhance localized therapeutic efficacy.²²

2. Nanoparticle Architecture & Synthesis:

Core Matrix:

Poly (lactic-co-glycolic acid) (PLGA) polymer encapsulating Paclitaxel (PTX), providing biocompatibility and sustained hydrophobic drug release.

Biomimetic Coating:

Cancer cell membrane (or alveolar surfactant lipid) coating, facilitating immune evasion and preventing early clearance by resident alveolar macrophages.

Targeting Moieties:

Conjugated with anti-EGFR (Epidermal Growth Factor Receptor) antibodies or Folate ligands to bind explicitly to overexpressed receptors on NSCLC cell surfaces.

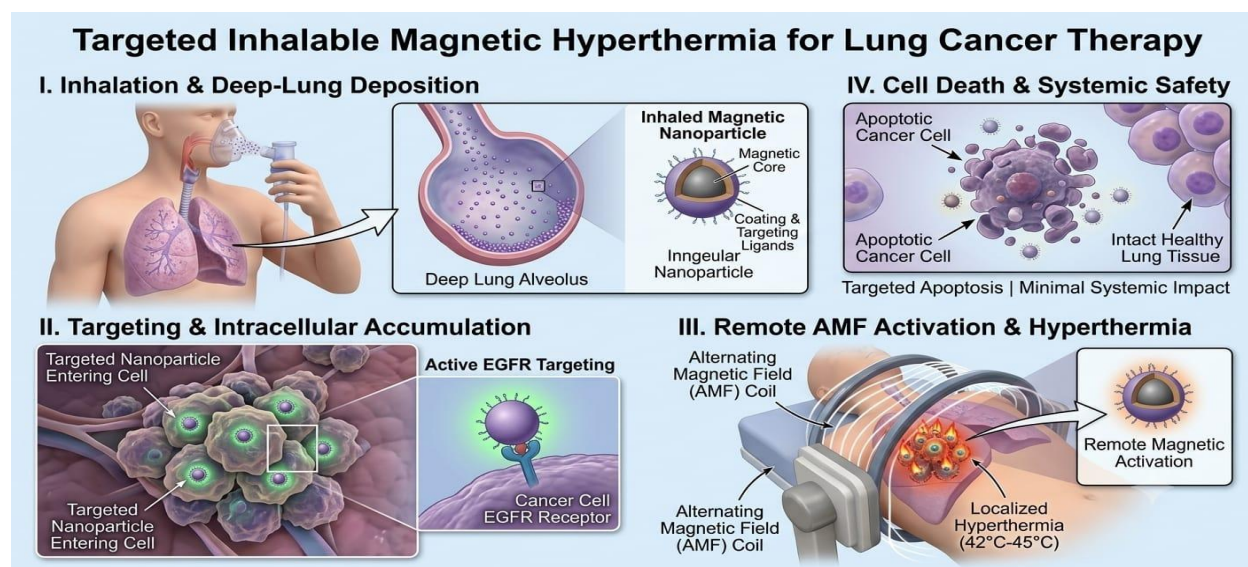


Figure No.7: Targeted Inhalable Magnetic Hyperthermia for Lung Cancer Therapy

3. Key Observations & Findings:

Extended Cellular Retention:

The biomimetic membrane coating significantly reduced uptake by alveolar macrophages, allowing extended residence time in the airway mucus lining and sustained tumor cell internalization via receptor-mediated endocytosis.

Tumor Regression & Apoptosis:

Histopathological evaluation demonstrated a marked increase in apoptotic tumor markers (e.g., elevated

Caspase-3 activity) and significant tumor volume suppression in Group B relative to control groups.

Reduced Systemic Toxicity:

Animals receiving inhaled targeted formulations showed no evidence of systemic neutropenia, hepatotoxicity, or organ damage compared to those receiving IV chemotherapy.²³

4. Translational Significance

This case study highlights that inhalable biomimetic nanoparticles directly bridge the gap between systemic

administration limits and localized pulmonary oncology. Direct airway deposition bypassing hepatic first-pass metabolism offers a clear pathway to increase therapeutic windows.²⁴

2) Hyaluronic Acid-Functionalized Biomimetic Nanoparticles for CD44-Targeted Combined Chemotherapy and Photothermal Therapy in Gastric Cancer

1. Background & Clinical Rationale

Gastric cancer (GC) remains a leading cause of cancer-related mortality globally. Conventional systemic

chemotherapy (e.g., using Doxorubicin, Cisplatin, or 5-Fluorouracil) faces major hurdles such as limited gastrointestinal permeability, rapid systemic degradation, severe organ toxicity, and therapeutic resistance driven by gastric cancer stem cells (CSCs).²⁵

2. Nanoparticle Design & Synthesis

Nanocarrier Core: Poly (lactic-co-glycolic acid) (PLGA) or Graphene Oxide Quantum Dots (GOQDs) acting as high-capacity drug carriers.

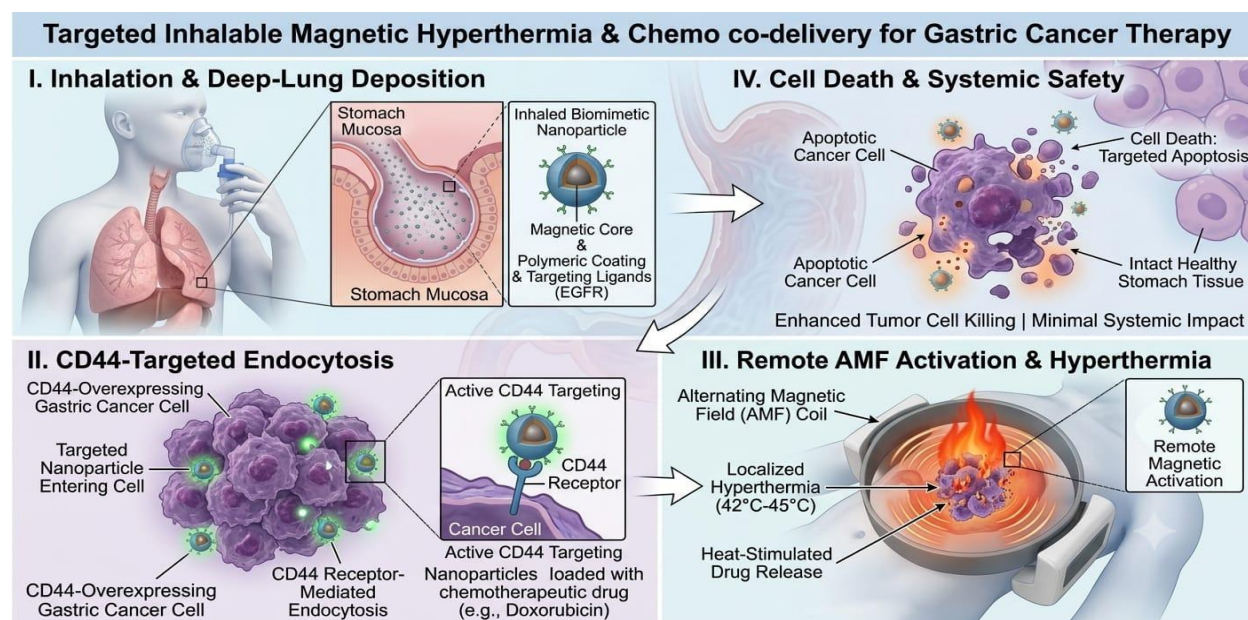


Fig No.8: Targeted Inhale Magnetic Hyperthermia and Chemo Co-delievery for Gastric Cancer Therapy

Chemotherapeutic Payload: Encapsulated Doxorubicin (DOX) or Cisplatin (CDDP) for controlled intracellular drug release.

Photothermal Agent: Gold Nano shells or Indocyanine Green (ICG) embedded to convert Near-Infrared (NIR) light into localized hyperthermic heat.

Targeting Shell: Surface modification with Hyaluronic Acid (HA) for active CD44 receptor targeting, integrated with biomimetic cell membranes to prolong blood circulation half-life and prevent immune clearance.²⁶

3.Key Findings & Results

Enhanced Cellular Endocytosis: HA-functionalized nanoparticles displayed significantly higher binding affinity and endocytic uptake in CD44-overexpressing

gastric cancer cells compared to non-targeted formulations.

Localized Thermal & Cytotoxic Ablation: NIR laser irradiation (808nm) triggered localized hyperthermia (42°C-45°C) in gastric tumor tissue, destabilizing tumor cell membranes and accelerating acidic intracellular drug release.

Tumor Growth Suppression: Group B achieved near-complete suppression of orthotopic gastric tumors in vivo without tumor recurrence or significant loss in total body weight.

Biocompatibility & Low Toxicity: Biomimetic surface coating prevented liver toxicity and off-target tissue damage typically caused by systemic free chemotherapy.²⁷

3) Trastuzumab-Conjugated Multifunctional Nanoparticles for HER2-Targeted Chemo-Photothermal Therapy in Breast Cancer

1. Background & Clinical Rationale

Human Epidermal Growth Factor Receptor 2 (HER2)-positive breast cancer accounts for roughly 15% - 20% of all invasive breast carcinomas. It is characterized by an aggressive tumor phenotype, high risk of metastasis, and poor prognosis under conventional therapies. Systemic administration of chemotherapeutic drugs such as Paclitaxel or Docetaxel often leads to severe cardiotoxicity, neutropenia, and off-target tissue damage.

This case study evaluates a multifunctional nanomedicine strategy utilizing Trastuzumab (anti-HER2 monoclonal antibody)-conjugated gold-polymeric nanoparticles. The system achieves high-affinity receptor recognition, targeted intracellular

drug accumulation, and synergistic chemo-photothermal tumor ablation under Near-Infrared (NIR) light irradiation.²⁸

2. Nanoparticle Design & Structural Architecture

Polymeric Core Matrix: Poly (lactic-co-glycolic acid) (PLGA) or liposomal core encapsulating Paclitaxel/Docetaxel for controlled, pH-sensitive intracellular drug release.

Photothermal Agent: Gold Nanorods (Au NRs) or Plasmonic Gold Nano shells embedded to convert NIR laser light into localized hyperthermic energy (42°C - 45°C).

Active Targeting Ligand: Trastuzumab (Herceptin) conjugated to the nanoparticle surface via PEG linkers, enabling explicit molecular binding to the extracellular domain of HER2 receptors.²⁹

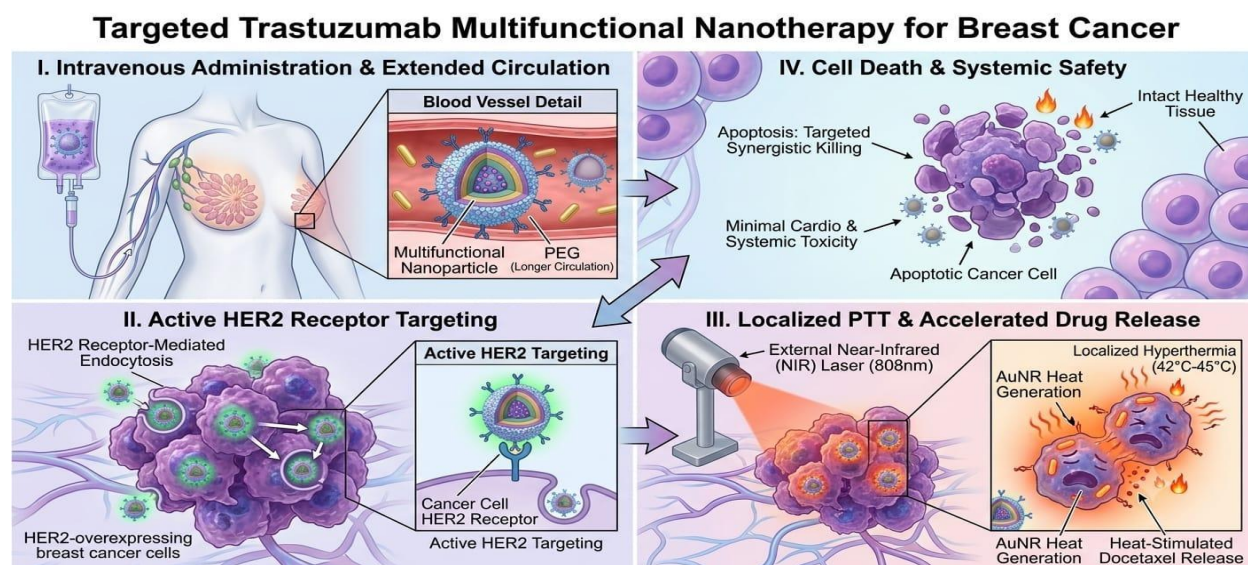


Fig No.9: Targeted Transtumuzab Multifunctional Nano therapy for Breast Cancer

3. Key Findings & Results

Specific Binding & Endocytosis: Trastuzumab-functionalized nanoparticles exhibited strong molecular binding affinity ($K_d \approx 0.1-5 \text{ nM}$) for HER2 receptors, inducing rapid receptor-mediated endocytosis in HER2-overexpressing breast cancer cells (SK-BR-3 / BT-474).⁽²⁹⁾

Synergistic Tumor Ablation: NIR laser irradiation triggered localized hyperthermia ($>42^{\circ}\text{C}$) within the tumor mass. The heat disrupted cellular membrane integrity and accelerated intracellular drug

release, yielding over 90% tumor volume suppression in vivo.

Cardioprotective & Systemic Safety: Localized thermal release and targeted binding significantly reduced systemic circulation of free chemotherapy, preventing the severe cardiotoxicity and neutropenia associated with standard systemic regimens.³⁰

REFERENCE

- [1] J. E. M. Farley, F. Lam, M. Laver Sanne, M. Colombe, M. Mery, *et al.*, "Global Cancer

- Observatory: Cancer Today,” International Agency for Research on Cancer, 2026. [Online]. Available: <https://gco.iarc.fr/today>.
- [2] E. Stolyarov-Foucher, M. Colombes, L. A. G. Ries, et al., “International incidence of childhood cancer, 2001–10: A population-based registry study,” *The Lancet Oncology*, vol. 18, no. 6, pp. 719–731, 2017.
- [3] H. Fink, O. Langsley, N. J. Vigo, H. Rumgay, J. Rehm, et al., “Global and regional cancer burden attributable to modifiable risk factors to guide prevention,” *Nature Medicine*, vol. 32, no. 4, pp. 1306–1315, 2026.
- [4] H. Sung, J. Farley, R. L. Siegel, M. Laver Sanne, I. Seromata, A. Jemal, and F. Bray, “Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries,” *CA: A Cancer Journal for Clinicians*, vol. 71, no. 3, pp. 209–249, 2021, doi: 10.3322/caac.2166.
- [5] D. Hanahan, “Hallmarks of cancer: New dimensions,” *Cancer Discovery*, vol. 11, no. 1, pp. 31–46, 2021, doi: 10.1158/2159-8290.CD-20-1780.
- [6] B. Vogelstein et al., “Cancer genome landscapes,” *Science*, vol. 339, no. 6127, pp. 1546–1558, 2013, doi: 10.1126/science.1235122.
- [7] R. A. Weinberg, *The Biology of Cancer*, 2nd ed. Garland Science, 2013, ISBN: 978-0815342205.
- [8] V. Snyder et al., “The heterogeneity of cancer stem cells: Dump trucks or cellular Ferrari drivers?” *Oncotarget*, vol. 9, no. 48, pp. 28834–28854, 2018, doi: 10.18632/oncotarget.2562.
- [9] H. Sung et al., “Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries,” *CA: A Cancer Journal for Clinicians*, vol. 71, no. 3, pp. 209–249, 2021, doi: 10.3322/caac.21660.
- [10] World Health Organization, “Cancer: Fact sheet,” 2024. [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/cancer>.
- [11] World Health Organization, “Lung cancer fact sheet,” 2024. [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/lung-cancer>.
- [12] National Cancer Institute, “Adult primary liver cancer treatment (PDQ®)—Health professional version,” 2023. [Online]. Available: <https://www.cancer.gov/types/liver/hp/adult-liver-treatment-pdq>.
- [13] American Society of Hematology, “Leukemia, lymphoma, and myeloma patient guidelines,” 2024. [Online]. Available: <https://www.hematology.org/education/patients/blood-cancers>.
- [14] “Biomedical nanotechnology related grand challenges and perspectives,” *Frontiers in Nanotechnology*, vol. 1, Art. no. 00001, 2019, doi: 10.3389/fnano.2019.00001.
- [15] M. C. Roco, “National Nanotechnology Initiative and a global vision for nanotechnology R&D,” *Journal of Nanoparticle Research*, vol. 5, no. 3, pp. 181–189, 2003.
- [16] X. Hou, T. Zaks, R. Langer, and Y. Dong, “Lipid nanoparticles for mRNA delivery,” *Nature Reviews Materials*, vol. 6, no. 12, pp. 1078–1094, 2021.
- [17] H. Yin, R. L. Kanasty, A. A. ElSohly, et al., “Non-viral vectors for gene-based therapy,” *Nature Reviews Genetics*, vol. 15, no. 8, pp. 541–555, 2014.
- [18] P. K. Jain, I. H. El-Sayed, and M. A. El-Sayed, “Au nanoparticles target cancer,” *Nano Today*, vol. 2, no. 1, pp. 18–29, 2007.
- [19] P. D. Howes, S. Rana, and M. M. Stevens, “Plasmonic nanomaterials for biosensing,” *Chemical Society Reviews*, vol. 43, no. 7, pp. 2117–2151, 2014.
- [20] National Nanotechnology Initiative, “What is nanotechnology?” [Online]. Available: <http://www.nano.gov/nanotech-101/what/definition>. [Accessed: Jul. 14, 2011].
- [21] M. Garcia, A. Jemal, E. M. Ward, M. M. Center, Y. Hao, R. L. Siegel, and M. J. Thun, *Global Cancer Facts & Figures*. Atlanta, GA, USA: American Cancer Society, 2007.
- [22] T. Sadhukha, T. S. Wiedmann, and J. Panyam, “Inhalable magnetic nanoparticles for targeted hyperthermia in lung cancer therapy,” *Biomaterials*, vol. 34, no. 21, pp. 5163–5171, 2013, doi: 10.1016/j.biomaterials.2013.03.06.
- [23] J. Wang et al., *Journal of Controlled Release*, vol. 210, pp. 60–68, 2015, doi: 10.1016/j.jconrel.2015.05.281.
- [24] J. Long et al., “Biomimetic graphene oxide quantum dots nanoparticles targeted

- photothermal-chemotherapy for gastric cancer,”
Journal of Drug Targeting, vol. 31, no. 5, pp. 523–
534, 2023, doi:
10.1080/1061186X.2022.2162060.
- [25] N. Liu et al., “Advances in nanomedicine and
delivery systems for gastric cancer,” *Frontiers in
Immunology*, vol. 16, Art. no. 1562766, 2025,
doi: 10.3389/fimmu.2025.1562766.
- [26] H. Moradian and A. Mohammadzadeh, “Targeted
drug delivery systems in gastric cancer: A
comprehensive review on nano-based strategies,”
Cancer Nanotechnology, vol. 14, no. 1, pp. 45–
62, 2023, doi: 10.1186/s12645-023-00189-.
- [27] A. Jahangiri et al., “Trastuzumab-conjugated
nanoliposomes for targeted capecitabine delivery
in HER2-positive breast cancer xenografts,”
International Journal of Nanomedicine, vol. 21,
pp. 3412–3428, 2026, doi: 10.2147/IJN.S458921.
- [28] Y. Wang et al., “Gold nanoparticle–trastuzumab
conjugates for HER2-positive breast cancer
treatment: Developments in radionuclide therapy,
multimodal imaging, and combination
strategies,” *Nano Select*, vol. 7, no. 3, Art. no.
e20260012, 2026, doi: 10.1002/nano.20260012.
- [29] S. Duan et al., “Photothermal and combinatory
therapy as an emerging paradigm for breast
cancer treatment,” *International Journal of
Nanomedicine*, vol. 18, pp. 5171–5192, 2023, doi:
10.2147/IJN.S551712.