JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# Applications of Nanotechnology in Cancer treatment

[1] **Sainath N. Ingole,** [2] **Prasanna P. Pipare**
[1] Assistant professor, 2 Student
[1] Shri Sambhaji College of Pharmacy, Khadkut

## ABSTRACT

Nanotechnology appears as a promising and innovative approach to cancer treatment and diagnosis. Nanotechnology has offered various methods to reduce deaths and improve the quality of life despite considerable progress in patient care still cancer remains the most destructive disease and the major cause of loss of life. cancer therapies have advanced substantially but there remains a shortfall in available therapies these diagnostic and therapeutic methods are not effective apart from the unproductive selection of cancerous cells and the toxicity of traditional chemotherapy remains the notable challenge. Early detection of cancer cells is among the leading steps toward ensuring the most desirable cancer treatment. In the battle against cancer, early detection of cancer cells is a crucial factor for a successful treatment early detection is important in improving patients' quality of life. Developing safer and more effective anti-cancer treatment approaches is of great interest. In recent decades nanotechnology has appeared as a promising and innovative approach for cancer treatment and diagnosis/ Nanotechnology has offered certain benefits in terms of cancer therapies by reducing chronic pain and its adverse effects and guiding the drugs to target cancer cells selectively and nanotechnology is being employed to improve diagnosis over the years. nanomaterials including carbon nanotubes and Quantum dots these nanomaterials have unique physical optical and electrical properties that are helpful in sensing cancerous cells. This review is focused on outlining the commonly used nanomaterials employed in cancer therapy and diagnosis and highlighting the potential applications of nanotechnology in oncology.

**Keywords**: Nanotechnology, cancer, Nanomaterials.

## INTRODUCTION

Cancer is a main cause of death and a global health problem it remains the most destructive disease and a vital cause of mortality worldwide. Cancer is a disease characterized by uncontrolled growth of cells that spreads to other parts of the body to cause death. Cancer is a complicated disease that progresses through a series of stages. which includes resistance to cell death (apoptosis), uncontrolled cell growth, alterations in cellular signaling, tissue invasion, metastasis, and angiogenesis. Cancer continues to remain the most destructive disease and a vital cause of mortality worldwide. Cancer generally begins as a localized tumor and can spread (metastasize) to distant sites in the body, making management difficult.[1] According to the WHO International Agency of Resources on Cancer ( GLOBOCAN) 2022 there are a total 1of 413316 new cases and 916822 deaths. In 2024 2001140 new cancer cases and 611720 cancer deaths are projected to occur in us[2]. Absolute numbers, Incidence, and Both sexes, in 2022 Continents are given below in a pie chart [3].

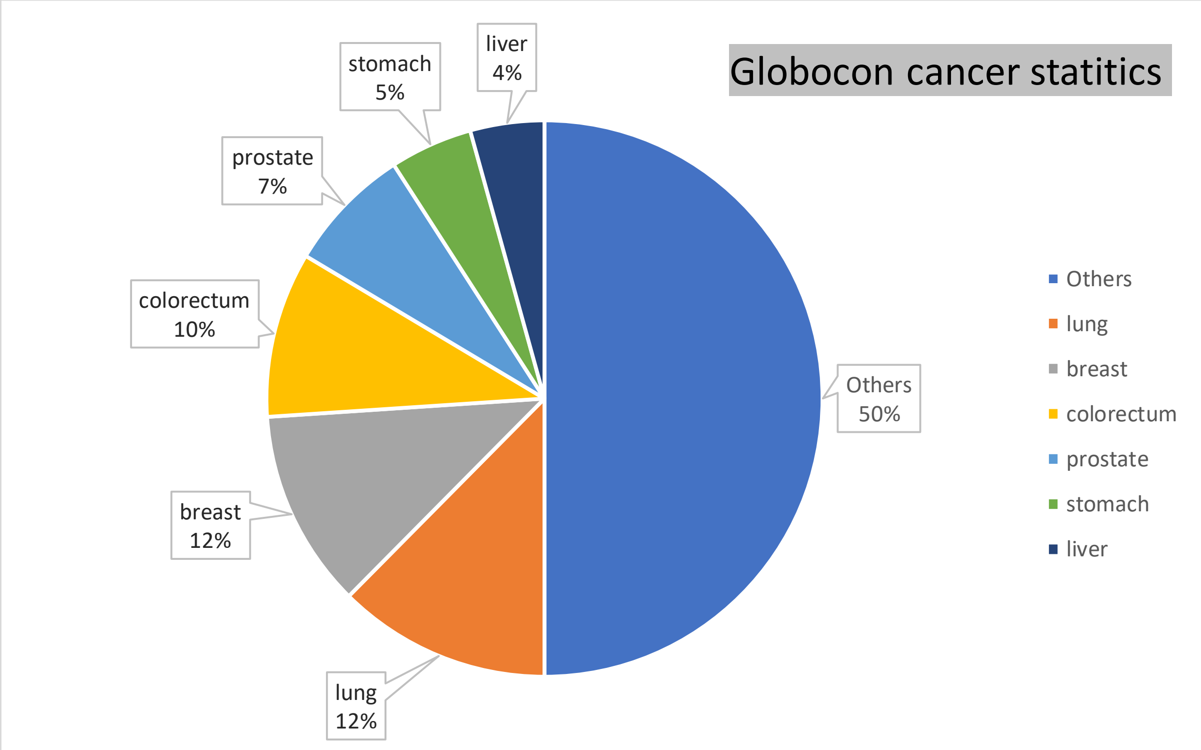


**Fig.1.** GLOBACAN 2022 CANCER STATICS [3]

The classic therapeutic options for cancer treatment are chemotherapy, radiotherapy, and surgery. The approach to treatment depends on different types of factors, including the stage and location of the cancer, as well as the patient's overall fitness, which is often compromised by the disease and further deteriorates with each long-term treatment intervention.[4] These treatments can lowers cancer repetitiveness and mortality but have some main side effects that can lead to critical complications and to the risk of death from other diseases [5] For these reasons, it is key to make sure earlier detection and treatment of cancers to reduce disease spread and mortalities. Nanotechnology has led to some promising results with its applications in the diagnosis and treatment of cancer, which include drug delivery, gene therapy, detection and diagnosis, drug carriage, biomarker mapping, targeted therapy, and molecular imaging. Nanotechnology has been applied in the development of nanomaterials [6] such as gold nanoparticles, and quantum dots, are used for cancer diagnosis at the molecular level. The development of biomarkers enables the accurate and fast detection of cancers [7] additionally, nanotechnology-based carriers, due to their unique biological properties, effortlessly cross cellular barriers. [8] Nanoparticles are used in medical applications because of their unique properties such as quantum properties, a surface-to-mass ratio much larger as compared to other particles, and an ability to carry other substances like probes, proteins, and drugs. The composition of nanoparticles can be diverse just as starting materials can be biological lipids, dextran, lactic acid, phospholipids, chitosan, or chemicals such as silica, carbon, metals, and different polymers.[9-12] Radiotherapy has been for a long time an essential tool against cancer, providing a possible cure, symptom relief, and extended survival. Nevertheless, it is linked to important side effects. When a patient is exposed to radiotherapy, not only are the tumoral cells targeted but the normal tissue around the tumor is also damaged [13]. For chemotherapy, there are many pharmacological classes that can be used in the treatment of cancer, showing side effects such as autoimmune disorders and lethal adverse events caused by the reactivation of cellular immunity[14] These traditional diagnostic methods however are not very powerful methods when it comes to cancer detection at very early stages. Some of the screening methods are much costliest and not available for every people. The scientific community leans on the use of nanotechnology, as a strategy with great potential to overcome these challenges. Therefore, the development of technology that is specific and reliable for detecting cancers at early stages. Nanotechnology and biomarkers two major fields in the building of strong diagnosis techniques that are being highly studied.

## NANOTECHNOLOGY FOR THE DETECTION OF CANCER BIOMARKERS

A biomarker is a sign of a biological state of disease it is characteristic of a specific state and therefore can be used as a marker for a target disease. Cancer biomarkers are biological features whose expression indicates the presence or state of a tumor. Such markers are used to study cellular processes and to monitor or identify changes in cancer cells, and these results could ultimately lead to a better understanding of tumors. The potential of screening for any cancer is limited by the clinical biology of the particular disease. Biomarkers can be proteins, protein fragments, or DNA. From them, the tumor biomarkers,, can be put to the test to verify the presence of specific tumors. Tumor biomarkers ideally should possess a high sensitivity (>75%) and specificity (99.6%)[15]. According to (NCI) National Cancer Institute biomarkers are biological molecules in blood, bodily fluids, or tissues that reveal a process, condition, or disease like cancer [16].

Types of cancer biomarkers are as follows

1) Genetic Biomarkers:

a) DNA as a Cancer Biomarker

In DNA cancer biomarkers engaging. Every cancer genome by the somatic alterations that differentiate it from the genome of non-neoplastic cells [17,18] Cancer has been related to uplifted levels of where DNA biomarkers can include oncogene alterations mutations in mismatch repair genes and mutations in tumor suppressor genes. These can all be used as DNA biomarkers. Mutations in the tumor genes such as the P53 tumor suppressor gene are present in over 50% of sporadic cancers and mutation in the oncogene such as KRAS oncogenes indicate the metastatic spread [19,20,21] The initial markers that are tested for tumor staging were circulating DNA, as shown in figure 2 [22].

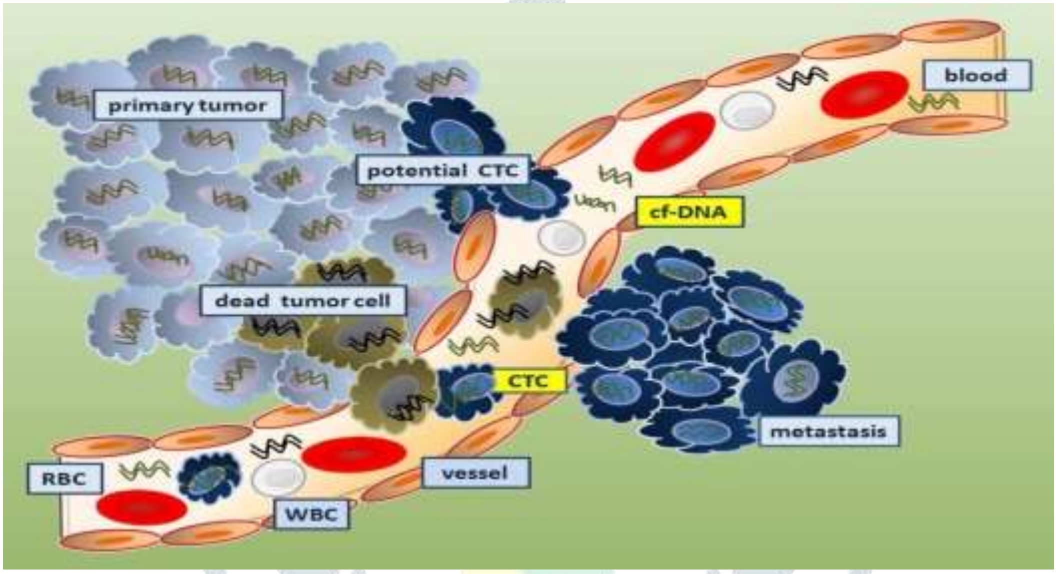


Fig**. 2.** The initial markers tested for tumor staging were circulating DNA

DNA from circulating malignant cells and free-floating cells can be found in the bloodstream. Circulating tumor cells (CTCs) gone through blood vessels after seperate from their primary site, contributing to metastasis in distant organs. In addition cell-free DNA (cf-DNA) is released into the bloodstream by dying cancer cells or proliferating tumors. RBC stands for red blood cells, and WBC refers to white blood cell. [22]

b) Mutations and Gene Alterations

Mutations and gene alterations are major cancer biomarkers that can provide precious data about the basic genetic changes that are driving the growth and progression of cancer. Here are some examples of mutation-and gene alteration-based cancer biomarkers are as follows in the BRAF V600E mutation that starts cell growth and assist the intended therapy selection in melanoma patients [23].

2) Proteins as Cancer Biomarkers

Amongst diagnostics that used in cancer are protein biomarkers are the first. Most of these biomarkers are based on the cancer enzymes, antigens, and hormones, but also when there is any change in protein glycosylation profile, which is the characteristic attribute of cancer. Glycans are the polymers of monosaccharides able to conjugate with the proteins to form glycoproteins. These conversely indicate glycans or glycoproteins are beneficial cancer biomarkers in tumor tissue, also in blood [24]. Proteins of pancreatic cancer may be found in several body fluids it may involve bile, pancreatic juice, urine, and fluid from pancreatic cysts,
as shown in figure 3 [25]. These proteins have a significant distribution of potential and may be rewarding biomarkers with a range of therapeutic applications, including early identification, illness staging, treatment prognosis, and in-flight patient monitoring.

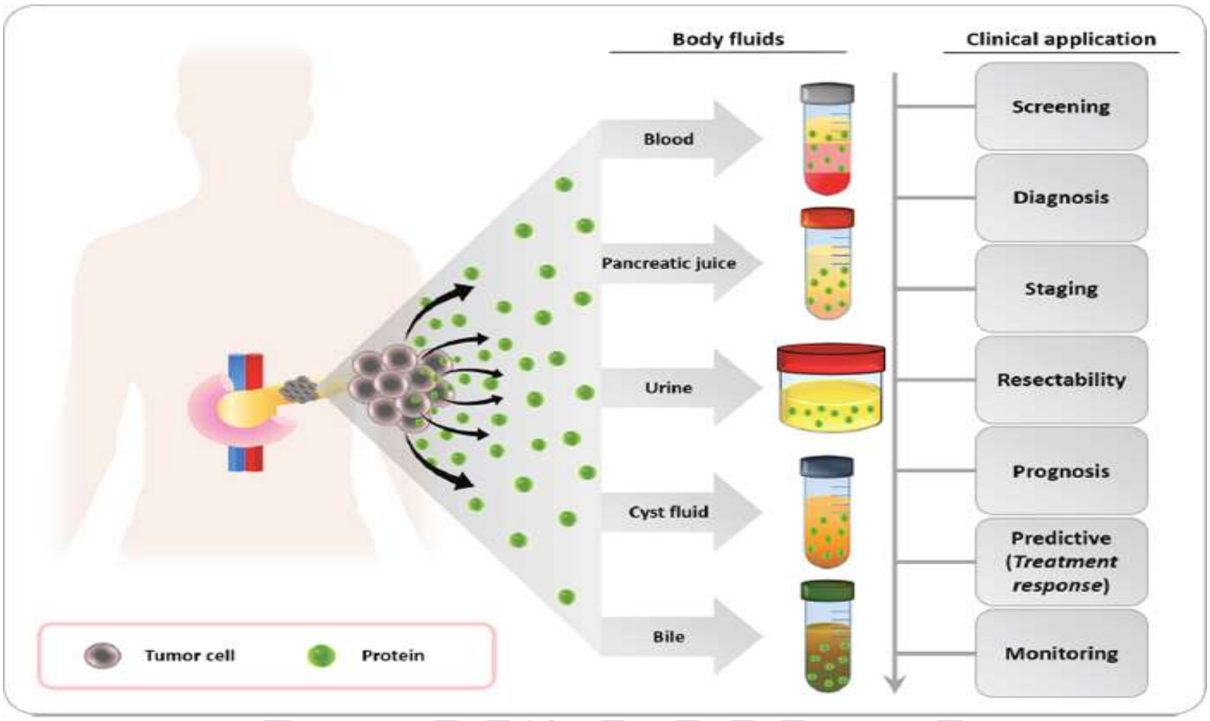


Fig.3**.** Body fluids for the identification of potential protein biomarkers for pancreatic cancer. [25]

Body fluids like pancreatic juice,blood, urine, pancreatic cyst fluid, and bile contain proteins derived from cancer cells. These proteins hold notable potential as tumor biomarkers and have various clinical applications in controlling pancreatic cancer patients. They can be used for screening individuals at high risk for pancreatic cancer, early diagnosis, determining disease stage, , predicting patient prognosis, guiding treatment decisions by estimate therapy response, and continuously monitoring patients in real-time. [25]

Some of the currently used biomarkers are listed below (table 1)

Table 1. Current cancer biomarkers in use

| Cancer | Markers | Characterstics | Typical sample |
|---|---|---|---|
| prostate | PSA (Prostate specific antigen), total and free | High sensitivity in all stages; also elevated from some non-cancer causes | Blood [26, 27] |
| | PSMA (Prostate specific membrane antigen | Levels tend to increase with age | Blood [28] |
| Breast | CA 15-3, 27, 29 (Cancer antigen 15-3, 27, 29) | Elevated in benign breast conditions. Either CA 15-3 or CA 27, 29 could be used as marker | Blood [26] |
| | Estrogen receptors | Overexpressed in hormone-dependent cancer | Tissue [29] |
| | Progesterone receptors | | Tissue [29] |
| Lung (non-small cell | CEA (Carcinoembryonic antigen) | Used in combination with NSA to increase specificity, used also for colon cancer detection | Blood [30] |
| Lung (small cell) | NSE (Neuron-specific enolase) | Better sensitivity towards specific types of lung caner | Blood [30] |
| Bladder | NMP22 (Matritech's nuclear matrix protein), BTA (Bladder tumor antigen | NMP-22 assays tend to have greater sensitivity than BTA assays | Urine[26,31] |
| Multiple myeloma and lymphomas | B2M (Beta-2 microglobulin) | Present in many other conditions, including prostate cancer and renal cell carcinoma | Blood [32] |
| | Monoclonal immunoglobulins | Overproduction of an immunoglobulin or antibody, usually detected by protein electrophoresis | Blood, urine [33] |
| Thyroid | Thyroglobulin | Principal iodoprotein of the thyroid gland | Serum, tissue [34] |
| Testicular | hCG (Human chorionic gonadotropin | May regulate vascular neoformation through vascular endothelial growth factor (VEGF) | Serum[26,35] |

## APPLICATIONS OF NANOTECHNOLOGY IN CANCER DIAGNOSIS

Gold nanoparticles

Gold nanoparticles (GNPs) existed in the bio-imaging spotlight owing to their unique optical attributes. GNPs with powerful surface-plasmon-enhanced absorption and scattering have authorized them to appear as powerful imaging labels and contrast agents. GNPs possess advanced absorption and scattering bands than conventional organic dyes, the cross-section of the bands extending to four to five orders of magnitude higher [36]. In addition, GNPs have been authenticated to be more biocompatible, less cytotoxic, and resistant to photobleaching corresponding to human cell experiments [37]. A supplementary unique property of the GNPs is the size-tunable optical properties. As intended to their size and shape, GNPs may absorb and scatter light amid the visible towards near-infrared (NIR) region [38]. The key advantage of AuNPs is that they aim at certain mechanisms for the transport of drugs. The AuNP aiming strategy is dependent on two non-identical mechanisms: passive targeting, in which the body pivots on inert nanoparticles, and active targeting, in which the surface of AuNPs is transformed to upgrade the preciseness toward the target molecule [39].

a) PASSIVE TARGETING

Passive targeting brings in the accumulation of nanoparticles, drugs, or antibiotics at judicious sites in tissues or cells grounded in their size and molecular weight. Colloidal nanoparticle technology has been employed in the treatment of liver cancer in a few studies and was map out in this manner that these nanoparticles are capable of passing through body organs but were possessed in the kidney [40].

Nanoparticles of size 150 nm can infiltrate easily into the sinus endothelium while particles greater than 250 nm it may be separated out by the spleen [41] Tumor vasculature are usually revealed more toward nanoparticles as correlates with normal tissues [42].

Gold nanoshells of size in the range of 130 nm can navigate through vessel walls but are retained within the tumor [40].

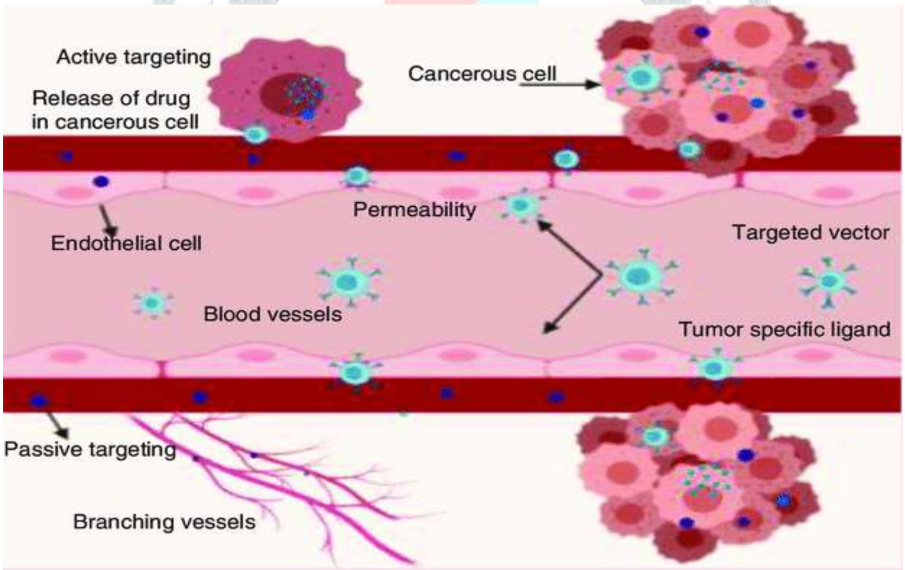


Fig. 4. Active and passive targeting of gold nanoparticles. Source [43].

b) ACTIVE TARGETING

In active targeting, the nanoparticle surface can be reformed by attachment using biomolecules such as the attachment of antibodies and ligands. The most main drawbacks of active targeting are the activation of the immune system of bacteria, which bin off the drugs, or reduce their insertion into the cell. PEG-coated nanoparticles are called as stealth particles that are invisible to the immune system of bacteria [40, 44, 45] PEG-coated AuNPs have high inclination toward porous membranes and their insertion power is higher than that of nonmodified AuNPs [46, 47].

**APPLICATIONS OF NANOTECHNOLOGY IN CANCER DIAGNOSIS**

NANOSHELLS

Nanoshells are round-shaped nanoparticles synthesized harnessing amphiphilic tercopolymorpholy and they are pH-sensitive doxorubicin encapsulated shell, which are coated with thin metallic shells to revamped biocompatibility and optical absorption. Hirsch et al. [48] have demonstrated that the surface of the nanoshells can be effortlessly operationalized for targeting applications. These nanoshells work by transforming plasma-mediated electrical energy into light energy and may be elastically twirled optically through UV-infrared emission/absorption arrays. Nanoshells are captative because their imaging is lacking the heavy metal toxicity [49] still their uses are restricted by their large sizes.

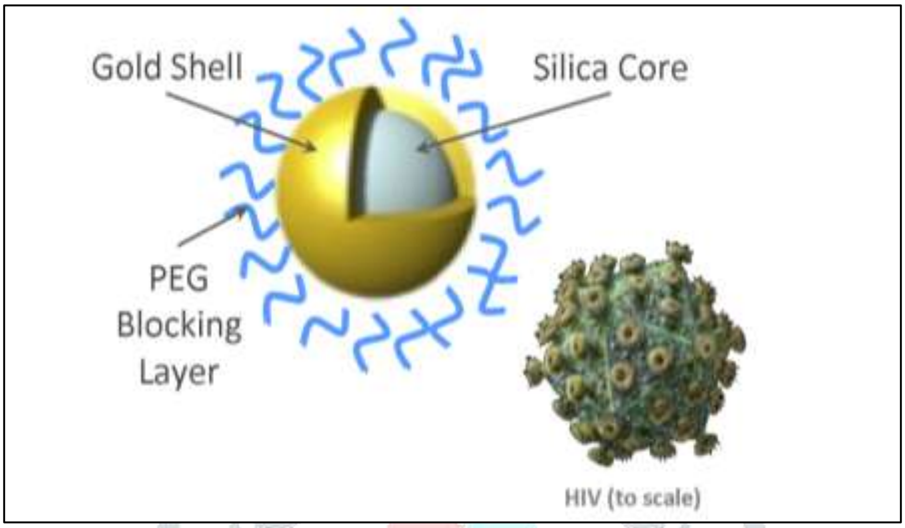


Fig.5 .Gold Nanoshell structure: Pic Courtesy Nanospectra Biosciences sources [50]

## APPLICATIONS OF NANOTECHNOLOGY IN CANCER THERAPY

Table 2. Currently Approved Cancer Drug Therapies Based on Nanotechnology [51]

| Product name | Nanoparticle material | indication | Approval year |
|---|---|---|---|
| vyxeos | Liposome | Acute myeloid leukemia | FDA (2017) EMA (2018) |
| onivyde | Liposome | Pancreatic cancer, colorectal cancer | FDA (2015) |
| Mepact | Liposome | Osteosarcoma | EMA (2009) |
| hensify | Hafnium oxide nanoparticle | Locally advanced soft tissue sarcoma (STS) | EMA (2019) |
| Genexol-PM | PEG-PLA polymeric micelle | Breast, lung, ovarian cancer | South Korea (2007) |
| Oncaspar | Polymer protein conjugate | Acute lymphoblastic leukemia | FDA (1994, 2006) |
| Abraxane | Nanoparticle-bound albumin | Breast and pancreatic cancer, non-small-cell lung cancer | FDA (2005) |

## APPLICATION OF NANOTECHNOLOGY IN CANCER THERAPY

### LIPOSOMES

Liposomes were first discovered by Alec D. Bangham in the 1960s Liposomes made up of non-toxic and biocompatible lipid bilayers, can serve as pharmaceutical carriers[52] .Liposomes are one of the utmost studied nanomaterials, which are nanoscale spheres composed of natural or synthesized phospholipid bilayer membrane and water phase nuclei [53]. heir core is aqueous, their head is hydrophilic, and the tails are hydrophobic, which means they are oriented away from the intercellular fluid. The conventional nanoparticle size is up to 100 nm and liposomes fluctuate between 90 and 150 nm. Liposomes are used to deliver the drug to the outer membrane of targeted tumor cells and, meanwhile, the fatty layer protects the enclosed drug [54] Liposomes can be incorporated from cholesterol and phospholipids and they have one distinct characteristic, which is their amphipathic nature, that empower them to stick to both hydrophilic and hydrophobic compounds. Specifically, they can summarize water-soluble drugs in their core and non-polar compounds in their bilayer membrane concurrently [55] Liposomes have other advantageous characteristics, like biocompatibility and biodegradability, and they absent toxicity or immunogenicity [56,57]. Moreover, the Food and Drug Administration (FDA) has already approved drug delivery systems based on liposomes like MyocetTM [58]. Liposomal drug delivery system source [59].

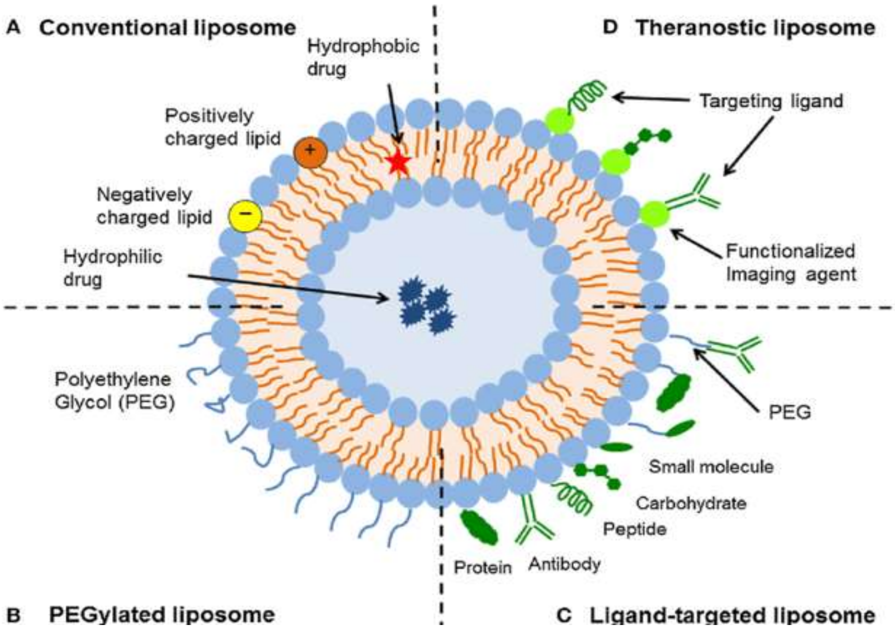


Fig.6. Liposomal drug delivery system source [59].

Liposomes have a role in portage to a peculiar target spot, decreasing biodistribution toxicity because of the surface-modifiable lipid composition, and have a configuration related to cell membranes. Liposome-grounded theranostics (particles constructed for the all together delivery of therapeutic and diagnostic moieties) have the benefit of marking certain cancer cells. Liposomes are more stable in the bloodstream and enlarge the solubility of the drug. They also serve as sustained-release composing and safeguard the drug from demeaning and pH changes, hence increasing the drug's circulating half-life. Liposomes help to conquer multidrug resistance. Drugs like doxorubicin, daunorubicin, mitoxantrone, paclitaxel, cytarabine, and irinotecan are used with liposome delivery [60-62].

**Table 3.** Liposome-based therapies for breast cancer currently in clinical use.

| Product name | Active agen | Approval year | Indication | Description of liposome | Composition | References |
|---|---|---|---|---|---|---|
| Lipodox®[a] | DOX HCl | 2012, USA[b] | Breast cancer | PEGylated stealth liposomes, ~100 nm | DSPC, CHOL, DSPE-PEG (2000) | 63 |
| Lipusu® | PTX | 2003, China | HER2-metastatic breast cancer | Non-PEGylated,~400 nm | Not available | 64,65 |

## APPLICATION OF NANOTECHNOLOGY IN CANCER THERAPY

QUANTUM DOTS

Quantum dots (QDs) are small particles or nanocrystals of semiconductor materials between 2 and 10 nanometers in size[66] these are semiconducting, light-emitting nanocrystals that have come out as a dominant molecular imaging agent since their exploration. QDs are a thrilling material to work with due to their unique optical characteristics compared to conventional organic fluorescent labels [67] In years, several QDs-based techniques like modification of QD conjugates and QD immunostaining have evolved. With the upgradation of multiplexing capability, QD conjugation to a great extent exceeds the monochromatic experiment in both time and cost-effectiveness [68] Besides, at low protein expression levels and in a low context, QD immunostaining is more accurate than traditional immunochemical methods. In cancer diagnosis, QD immunostaining is a potential tool for the recognition of different tumor biomarkers, like as a cell protein or other components of a heterogeneous tumor sample[ [69] Organic fluorescent dyes have various drawbacks that have bound their effectiveness as molecular imaging tags. Their low photobleaching threshold and broad absorption/emission peak width have obstructed their use in long-term imaging and multiplexing (detecting multiple labels simultaneously) [70] The recent advancement in surface changes of QDs, which combine with biomolecules, comprising peptides and antibodies, in vivo, can be utilized to target tumors and make possible their potential applications in cancer imaging and treatment. few studies combine QDs with prostate-specific antigens to label cancer, although others use QDs to make biomarkers that speed up the process with such immune creators having a more stable light intensity than traditional fluorescent immunomarkers..[71] Some applications of quantum dots are given below in the diagram [72].

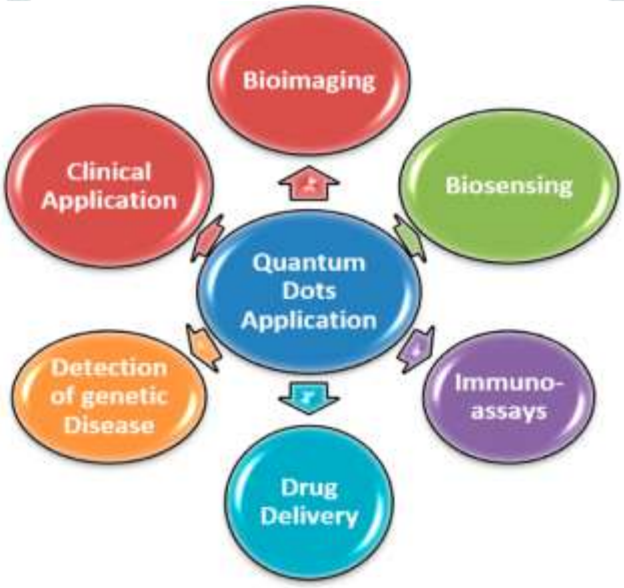


Fig.7. Different application of quantum dots.[72]

## CONCLUSION

Nanotechnology has revolutionized the field of oncology by providing innovative solutions for both the diagnosis and treatment of cancer. Some key applications in cancer diagnosis and cancer therapies have been summarize in this review. In diagnostics, advancements such as nanoshells and gold nanoparticles have significantly improved the specificity of biomarker detection, enabling earlier identification of cancer.

In cancer therapy, nanotechnology-based approaches, including liposomes and quantum dots have shown exceptional potential in delivering targeted treatments and lowering toxicity. Quantum dots offer precise imaging capabilities for tumors. liposomes improve drug delivery, ensuring that therapeutic agents are successfully directed to cancerous tissues.

Overall, the applications of nanotechnology in cancer represent a standard shift in how we approach the most complex diseases of our time. By uniting nanotechnology with existing and emerging biomedical technologies, we can develop more effective diagnostic tools and therapeutic strategies.

## REFERENCES


1. Reichert JM, Wenger JB. Development trends for new cancer therapeutics and vaccines. *Drug Discov Today*. 2008;13(1–2):30–37. doi: 10.1016/j.drudis.2007.09.003
2. Ferlay J, Ervik M, Lam F, Laversanne M, Colombet M, Mery L, Piñeros M, Znaor A, Soerjomataram I, Bray F (2024). Global Cancer Observatory: Cancer Today. Lyon, France: International Agency for Research on Cancer. Available from: [https://gco.iarc.who.int/today, accessed.]
3. Absolute numbers, Incidence, Both sexes, in 2022 Continents are given below in a pie chart Source:GLOBOCAN 2022, Available at International Agency for Research on Cancer (IARC https://gco.iarc.who.int)
4. Reijneveld, E.A.; Bor, P.; Dronkers, J.J.; Argudo, N.; Ruurda, J.P.; Veenhof, C. Impact of Curative Treatment on the Physical Fitness of Patients with Esophageal Cancer: A Systematic Review and Meta-Analysis. *Eur. J. Surg. Oncol.* 2022, *48*, 391–402.
5. Kerr, A.J.; Dodwell, D.; McGale, P.; Holt, F.; Duane, F.; Mannu, G.; Darby, S.C.; Taylor, C.W. Adjuvant and Neoadjuvant Breast Cancer Treatments: A Systematic Review of Their Effects on Mortality. *Cancer Treat. Rev.* **2022**, *105*, 102375.
6. Hu J, Huang W, Huang S, ZhuGe Q, Jin K, Zhao Y. Magnetically active Fe3O4 nanorods loaded with tissue plasminogen activator for enhanced thrombolysis. Nano Research. 2016;9:2652–61.
7. ran S, Degiovanni PJ, Piel B, Rai PJC, Medicine T. Cancer nanomedicine: a review of recent success in drug delivery. 2017; 6: 44.
8. Chaturvedi VK, Singh A, Singh VK, Singh MP. Cancer Nanotechnology: A New Revolution for Cancer Diagnosis and Therapy. Current drug metabolism. 2019;20:416–29. doi: 10.2174/1389200219666180918111528.
9. Jani P, Subramanian S, Korde A, Rathod L, Sawant KK. Theranostic nanocarriers in cancer: dual capabilities on a single platform. In: *Functional Bionanomaterials*. Springer; 2020:293–312.
10. Nikolova M, Slavchov R, Nikolova G. Nanotechnology in medicine. In: *Drug Discovery and Evaluation: Methods in Clinical Pharmacology*. Springer; 2020:533–546
11. Saxena SK, Nyodu R, Kumar S, Maurya VK. Current advances in nanotechnology and medicine. In: *NanoBioMedicine*. Springer; 2020:3–16.
12. Mukherjee A, Bhattacharyya S. Nanotechnology in medicine. In: *Biotechnology Business-Concept to Delivery*. Springer; 2020:57–64.
13. Chen, Y.H.; Molenaar, D.; Uyl-de Groot, C.A.; van Vulpen, M.; Blommestein, H.M. Medical Resource Use and Medical Costs for Radiotherapy-Related Adverse Effects: A Systematic Review. *Cancers* 2022, *14*, 2444.
14. dverse Events of Immune Checkpoint Inhibitors Therapy for Urologic Cancer Patients in Clinical Trials: A Collaborative Systematic Review and Meta-Analysis—ScienceDirect. Available online: https://www.sciencedirect.com/science/article/pii/S0302283822000653 (accessed on 25 January 2023).
15. Das PM, Bast RC Jr. Early detection of ovarian cancer. Biomark Med. 2008;2:291–303. doi: 10.2217/17520363.2.3.291.
16. Allred D.C. Commentary: Hormone receptor testing in breast cancer: A distress signal from Canada. Oncologist. 2008;13:1134–1136. doi: 10.1634/theoncologist.2008-0184.
17. Vogelstein B, Papadopoulos N, Velculescu VE, Zhou S, Diaz LA Jr., Kinzler KW. Cancer genome landscapes. Science 2013;339(6127):1546–58 doi 10.1126/science.1235122.
18. Tomasetti C, Vogelstein B, Parmigiani G. Half or more of the somatic mutations in cancers of self-renewing tissues originate prior to tumor initiation. Proc Natl Acad Sci U S A 2013;110(6):1999–2004 doi 10.1073/pnas.1221068110.
19. Tangella L.P., Clark M.E., Gray E.S. Resistance mechanisms to targeted therapy in BRAF-mutant melanoma-A mini review. Biochim. Biophys. Acta (BBA)-Gen. Subj. 2021;1865:129736. doi: 10.1016/j.bbagen.2020.129736.

20. Passaro A., Mok T., Peters S., Popat S., Ahn M.-J., De Marinis F. Recent advances on the role of EGFR tyrosine kinase inhibitors in the management of NSCLC with uncommon, non exon 20 insertions, EGFR mutations. J. Thorac. Oncol. 2021;16:764–773. doi: 10.1016/j.jtho.2020.12.002.
21. Zenonos K., Kyprianou K. RAS signaling pathways, mutations and their role in colorectal cancer. World J. Gastrointest. Oncol. 2013;5:97. doi: 10.4251/wjgo.v5.i5.97.
22. in H., Ma Y., Shen Q., Wang X. Methylation: From DNA, RNA and Histones to Diseases and Treatment. InTech; London, UK: 2012. Circulating methylated DNA as biomarkers for cancer detection; p. 137.
23. Tangella L.P., Clark M.E., Gray E.S. Resistance mechanisms to targeted therapy in BRAF-mutant melanoma-A mini review. Biochim. Biophys. Acta (BBA)-Gen. Subj. 2021;1865:129736. doi: 10.1016/j.bbagen.2020.129736.
24. Stowell S.R., Ju T., Cummings R.D. Protein Glycosylation in Cancer. Annu. Rev. Pathol. 2015;10:473–510. doi: 10.1146/annurev-pathol-012414-040438.
25. Jimenez-Luna C., Torres C., Ortiz R., Dieguez C., Martinez-Galan J., Melguizo C., Prados J.C., Caba O. Proteomic biomarkers in body fluids associated with pancreatic cancer. Oncotarget. 2018;9:16573. doi: 10.18632/oncotarget.24654.
26. Ludwig J., Weinstein J. Biomarkers in cancer staging, prognosis and treatment selection. Nature Rev. Cancer. 2005;5:845–856. doi: 10.1038/nrc1739.
27. Catalona W. Clinical utility of measurements of free and total prostate-specific antigen (PSA): a review. Prostate. 1996;7:64–69. doi: 10.1002/(sici)1097-0045(1996)7+<64::aid-pros9>3.0.co;2-j.
28. Beckett M., Cazares L., Vlahou A., Schellhammer P., Wright G. Prostate-specific membrane antigen levels in sera from healthy men and patients with benign prostate hyperplasia or prostate cancer. Clin. Cancer Res. 1995;5:4034–4040.
29. Henderson C., Patek A. The relationship between prognostic and predictive factors in the management of breast cancer. Breast Cancer Res. Treat. 1998;52:261–288. doi: 10.1023/a:1006141703224.
30. Molina R., Auge J., Escudero J., Marrades R., Vinolas N., Carcereny E., Ramirez J., Filella X. Mucins CA 125, CA 19.9, CA 15.3 and TAG-72.3 as tumor markers in patients with lung cancer: comparison with CYFRA 21-1, CEA, SCC and NSE. Tumor Biol. 2008;29:371–380. doi: 10.1159/000181180.
31. Landman J., Chang Y., Kavaler E., Droller M., Liu B. Sensitivity and specificity of NMP-22, telomerase, and BTA in the detection of human bladder cancer. Urology. 1998;52:398–402. doi: 10.1016/s0090-4295(98)00219-2.
32. Bataille R., Grenier J., Commes T. In vitro production of beta2 microglobulin by human myeloma cells. Canc. Investig. 1988;6:271–277. doi: 10.3109/07357908809080649.
33. Cordoba F., Lavabre-Bertrand T., Salhi S., Huglet M., Gerfaux J., Rossi J., Vendrell J. Spontaneous monoclonal immunoglobulin-secreting peripheral blood mononuclear cells as a marker of disease severity in multiple myeloma. Br. J. Haematol. 2000;108:549–558. doi: 10.1046/j.1365-2141.2000.01899.x.
34. Pacini F., Pinchera A. Serum and tissue thyroglobulin measurement: clinical applications in thyroid disease. Biochimie. 1999;81:463–467. doi: 10.1016/s0300-9084(99)80096-0.
35. Arrieta O., Michel Ortega R., Angeles-Sanchez J., Villarreal-Garza C., Aviles-Salas A., Chanona-Vilchis J., Arechaga-Ocampo E., Luevano-Gonzalez A., Jimenez M., Aguilar J. Serum human chorionic gonadotropin is associated with angiogenesis in germ cell testicular tumors. J. Exp. Clin. Canc. Res. 2009;28:120. doi: 10.1186/1756-9966-28-120.
36. Jain P., Lee K., El-Sayed I., El-Sayed M. Calculated absorption and scattering properties of gold nanoparticles of different size, shape, and composition: applications in biological imaging and biomedicine. J. Phys. Chem. B. 2006;110:7238–7248. doi: 10.1021/jp057170o.
37. Connor E., Mwamuka J., Gole A., Murphy C., Wyatt M. Gold nanoparticles are taken up by human cells but do not cause acute cytotoxicity. Small. 2005;1:325–327. doi: 10.1002/smll.200400093.
38. Kim B., Tripp S., Wei A. Tuning the optical properties of large gold nanoparticle arrays. Mater. Res. Soc. Symp. Proc. 2002;676:Y6.1.1–Y6.1.7.
39. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1983)
40. Moghimi SM, Hunter AC, Murray JC. Nanomedicine: current status and future prospects. FASEB J. 19(3), 311–330 (2005)
41. O'Neal DP, Hirsch LR, Halas NJ, Payne JD, West JL. Photo-thermal tumor ablation in mice using near infrared-absorbing nanoparticles. Cancer Lett. 209(2), 171–176 (2004)
42. Jain RK, Booth MF. What brings pericytes to tumor vessels? J. Clin. Invest. 112(8), 1134–1136 (2003
43. Recent Advances in Combinatorial Cancer Therapy Via Multifunctionalized Gold Nanoparticles - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Active-and-

passive-targeting-of-gold-nanoparticles-A-In-passive-targeting-gold_fig3_341180870 [accessed 10 Dec 2024].
44. Love JC, Estroff LA, Kriebel JK, Nuzzo RG, Whitesides GM. Self-assembled monolayers of thiolates on metals as a form of nanotechnology. Chem. Rev. 105(4), 1103–1170 (2005)
45. Dobrovolskaia MA, McNeil SE. Immunological properties of engineered nanomaterials. Nat. Nanotechnol. 2(8), 469 (2007)
46. Choi SW, Kim WS, Kim JH. Surface modification of functional nanoparticles for controlled drug delivery. J. Dispers. Sci. Technol. 24(3–4), 475–487 (2003).
47. Paciotti GF, Kingston DG, Tamarkin L. Colloidal gold nanoparticles: a novel nanoparticle platform for developing multifunctional tumor-targeted drug delivery vectors. Drug Dev. Res. 67(1), 47–54 (2006)
48. Hirsch LR, Gobin AM, Lowery AR, et al. Metal nanoshells. Ann Biomed Eng. 2006;34:15–22. doi: 10.1007/s10439-005-9001-8.
49. Nunes T, Pons T, Hou X, Van Do K, Caron B, Rigal M. et al. Pulsed-laser irradiation of multifunctional gold nanoshells to overcome trastuzumab resistance in HER2-overexpressing breast cancer. Journal of experimental & clinical cancer research: CR. 2019;38:306. doi: 10.1186/s13046-019-1305-x.
50. Available at [ https://www.aj-stem.com/post/gold-nanoshells-and-focal-laser-therapy-a-novel-approach-to-solid-tumor-(treatmenthttps://static.wixstatic.com/media/f5bb99_e7459f27…c/f5bb99_e7459f27f1464770a7a581fcf78db700~mv2.png)
51. (EMA: European Medicines Agency; FDA: US Food and Drug Administration; Adapted from Andreas Wicki, et al., J Control Release, 2015 and Francisco Rodriguez, et al., *Biomolecules*, 2022)
52. Al-Jamal W., Kostarelos K. Liposomes: From a Clinically Established Drug Delivery System to a Nanoparticle Platform for Theranostic Nanomedicine. Acc. Chem. Res. 2011;44:1094–1104. doi: 10.1021/ar200105p.
53. Malam Y, Loizidou M, Seifalian AM. Liposomes and nanoparticles: nanosized vehicles for drug delivery in cancer. Trends in pharmacological sciences. 2009;30:592–9. doi: 10.1016/j.tips.2009.08.004.
54. Saraf S., Jain A., Tiwari A., Verma A., Panda P.K., Jain S.K. Advances in Liposomal Drug Delivery to Cancer: An Overview. J. Drug Deliv. Sci. Technol. 2020;56:101549. doi: 10.1016/j.jddst.2020.101549.
55. Lungu I.I., Grumezescu A.M., Volceanov A., Andronescu E. Nanobiomaterials Used in Cancer Therapy: An up-to-Date Overview. Molecules. 2019;24:3547. doi: 10.3390/molecules24193547.
56. Olusanya T.O.B., Haj Ahmad R.R., Ibegbu D.M., Smith J.R., Elkordy A.A. Liposomal Drug Delivery Systems and Anticancer Drugs. Molecules. 2018;23:907. doi: 10.3390/molecules23040907.
57. Zhou Q., Zhang L., Wu H. Nanomaterials for Cancer Therapies. Nanotechnol. Rev. 2017;6:473–496. doi: 10.1515/ntrev-2016-0102.
58. Mross K., Niemann B., Massing U., Drevs J., Unger C., Bhamra R., Swenson C.E. Pharmacokinetics of Liposomal Doxorubicin (TLC-D99; Myocet) in Patients with Solid Tumors: An Open-Label, Single-Dose Study. Cancer Chemother. Pharmacol. 2004;54:514–524. doi: 10.1007/s00280-004-0825-y.
59. Smart nanocarrier-based drug delivery systems for cancer therapy and toxicity studies: A review Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Schematic-representation-of-the-different-types-of-liposomal-drug-delivery-systems-A_fig1_325972002 [accessed 11 Dec 2024]
60. Chatterjee P., Kumar S. Current Developments in Nanotechnology for Cancer Treatment. Mater. Today Proc. 2022;48:1754–1758. doi: 10.1016/j.matpr.2021.10.048.
61. Bozzuto G, Molinari A: Liposomes as nanomedical devices. Int J Nanomedicine. 2015, 10:975-99. 10.2147/IJN.S68861
62. Allen TM, Cullis PR: Liposomal drug delivery systems: from concept to clinical applications . Adv Drug Deliv Rev. 2013, 65:36-48. 10.1016/j.addr.2012.09.037
63. Burade, V., Bhowmick, S., Maiti, K. et al. Lipodox® (generic doxorubicin hydrochloride liposome injection): in vivo efficacy and bioequivalence versus Caelyx® (doxorubicin hydrochloride liposome injection) in human mammary carcinoma (MX-1) xenograft and syngeneic fibrosarcoma (WEHI 164) mouse models. *BMC Cancer* **17**, 405 (2017). https://doi.org/10.1186/s12885-017-3377-3
64. Xu, X., Wang, L., Xu, H.-Q., Huang, X.-E., Qian, Y.-D., & Xiang, J. (2013, April 30). Clinical Comparison between Paclitaxel Liposome (Lipusu®) and Paclitaxel for Treatment of Patients with Metastatic Gastric Cancer. Asian Pacific Journal of Cancer Prevention. Asian Pacific Organization for Cancer Prevention. https://doi.org/10.7314/apjcp.2013.14.4.2591
65. Wang, H., Cheng, G., Du, Y., Ye, L., Chen, W., Zhang, L. ... Fu, F. (2013). Hypersensitivity reaction studies of a polyethoxylated castor oil-free, liposome-based alternative paclitaxel formulation. Molecular Medicine Reports, 7, 947-952. https://doi.org/10.3892/mmr.2013.1264

66. Ekimov AI, Onushchenko AAJJL. Quantum Size Effect in Three-Dimensional Microscopic Semiconductor Crystals. 1981; 34: 363.
67. Resch-Genger, U.; Grabolle, M.; Cavaliere-Jaricot, S.; Nitschke, R.; Nann, T. Quantum dots versus organic dyes as fluorescent labels. Nat. Methods 2008, 5, 763–775.
68. In years, several QDs based techniques like modification of QD conjugates and QD immunostaining have been evolved. With the upgradation of multiplexing capability, QDs conjugation to an great extent exceeds the monochromatic experiment in both time and cost-effectiveness
69. Xiang QM, Wang LW, Yuan JP, Chen JM, Yang F, Li Y. Quantum dot-based multispectral fluorescent imaging to quantitatively study co-expressions of Ki67 and HER2 in breast cancer. Experimental and molecular pathology. 2015;99:133–8. doi: 10.1016/j.yexmp.2015.06.013.
70. Schröck, E.; du Manoir, S.; Veldman, T.; Schoell, B.; Wienberg, J.; Ferguson-Smith, M.; Ning, Y.; Ledbetter, D.; Bar-Am, I.; Soenksen, D.; Garini, Y.; Ried, T. Multicolor spectral karyotyping of human chromosomes. *Science* **1996**, *273*, 494–497.
71. Ruan Y, Yu W, Cheng F, Zhang X, Rao T, Xia Y. et al. Comparison of quantum-dots- and fluorescein-isothiocyanate-based technology for detecting prostate-specific antigen expression in human prostate cancer. IET nanobiotechnology. 2011;5:47. doi: 10.1049/iet-nbt.2010.0016.
72. Singh, S., Dhawan, A., Karhana, S., Bhat, M., & Dinda, A. K. (2020). Quantum Dots: An Emerging Tool for Point-of-Care Testing. *Micromachines*, *11*(12), 1058. https://doi.org/10.3390/mi11121058.
73. Paciotti GF, Kingston DG, Tamarkin L. Colloidal gold nanoparticles: a novel nanoparticle platform for developing multifunctional
74. tumor-targeted drug delivery vectors. Drug Dev. Res. 67(1), 47–54 (2006)
75. Choi SW, Kim WS, Kim JH. Surface modification of functional nanoparticles for controlled drug delivery. J. Dispers. Sci. Technol.
76. 24(3–4), 475–487 (2003).
77. 165. Dobrovolskaia MA, McNeil SE. Immunological properties of engineered nanomaterials. Nat. Nanotechnol. 2(8), 469 (2007).
78. 166. Choi SW, Kim WS, Kim JH. Surface modification of functional nanoparticles for controlled drug delivery. J. Dispers. Sci. Technol.
79. 24(3–4), 475–487 (2003)
80. 165. Dobrovolskaia MA, McNeil SE. Immunological properties of engineered nanomaterials. Nat. Nanotechnol. 2(8), 469 (2007).
81. 166. Choi SW, Kim WS, Kim JH. Surface modification of functional nanoparticles for controlled drug delivery. J. Dispers. Sci. Technol.
82. 24(3–4), 475–487 (2003)
83. Love JC, Estroff LA, Kriebel JK, Nuzzo RG, Whitesides GM. Self-assembled monolayers of thiolates on metals as a form of
84. nanotechnology. Chem. Rev. 105(4), 1103–1170 (2005)
85. Love JC, Estroff LA, Kriebel JK, Nuzzo RG, Whitesides GM. Self-assembled monolayers of thiolates on metals as a form of
86. nanotechnology. Chem. Rev. 105(4), 1103–1170 (2005)
87. O'Neal DP, Hirsch LR, Halas NJ, Payne JD, West JL. Photo-thermal tumor ablation in mice using near infrared-absorbing
88. nanoparticles. Cancer Lett. 209(2), 171–176 (2004)
89. O'Neal DP, Hirsch LR, Halas NJ, Payne JD, West JL. Photo-thermal tumor ablation in mice using near infrared-absorbing
90. nanoparticles. Cancer Lett. 209(2), 171–176 (2004)
91. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH
92. Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1983)
93. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH
94. Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1983)
95. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH
96. Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1983)
97. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH

98. Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1983)

99. Bohren CF, Huffman DR. Absorption and scattering by a sphere. In: Absorption and Scattering of Light by Small Particles. WILEY-VCH

100. Verlag GmbH & Co. KGaA, NY, USA, 82–129 (1