Harnessing Nanobots for Early Detection and Targeted Treatment of Cancer

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***Abstract*—Nanobots have emerged as a promising tool in cancer treatment, offering targeted and efficient delivery of therapeutic agent. The review heighlight recent advances in nanobots design, fabrication and application in cancer therapy. Numerous tumors are extremely difficult to diagnose and identify. The development of innovative, highly sensitive, efficacious, diagnostic and therapeutic approaches is crucial for the management of cancer. Nanorobots have the potential to transport and administer substantial doses of anti-cancer medications to malignant cells while sparing healthy cells, therefore mitigating the adverse effects of present therapies such as damage from traditional chemotherapy. Nanobots are being used more and more in cancer detection and therapeutic treatment as a result of advancements in nanotechnology. By employing nanorobotic technology, the medication can be directed to a specific site, enhancing its effectiveness and minimizing the likelihood of side effects.**

***Index Terms*—Biosensor, Nanorobotic, Nanobots, Targeted drug delivery, Cancer therapy,etc.**

I. INTRODUCTION

Cancer is a serious disease that affects people of all socioeconomic backgrounds, regardless of age, including both children and adults. The word "cancer" comes from Hippocrates, who introduced a theory related to four body fluids: blood, phlegm, yellow bile, and black bile, proposing that an accumulation of black bile results in the development of cancer.[1] This disease ranks among the foremost causes of mortality globally, with approximately 7.6 million lives lost annually, representing 13% of total deaths. Projections indicate that cancer-related fatalities may escalate to 13.1 million by the year 2030. It is important to understand that cancer is not just one disease; instead, it consists of a diverse group of diseases, each with distinct characteristics that affect different organs or systems. Medical nanorobots, which are defined as nanoscale structures without fixed measurements that are outfitted with engines able to transform various energy types into mechanical movement, are designed to perform medical functions at the cellular level. Their diminutive size allows them to interact directly with cells, even penetrating them to access cellular machinery [3]. Key roles of nanorobotics in treating cancer involve locating and eliminating cancer cells, along with employing chemical biosensors for the prompt detection of tumor cells within a patient's body. Nanorobots can efficiently destroy cancer cells and help to clear obstructions in blood vessels, as well as possibly repair damaged DNA cells.[4] Researchers have concluded that lifestyle changes, dietary habits, environmental factors, and the proliferation of various industries contribute to the rise of cancer by increasing exposure to radiation and carcinogens.[5] Due to progress in nanotechnology, medical treatments have significantly expanded, with DNA nanobots being utilized to identify various types of cancer cells.[6] Consequently, this review article primarily aims to emphasize the significance, functionality, varieties, and applications of nanorobots, particularly in the context of DNA-based cancer therapies.[7]

A. Types of nanobots in cancer treatment:

Different types of nanobots in cancer treatment they are shown in a chart:

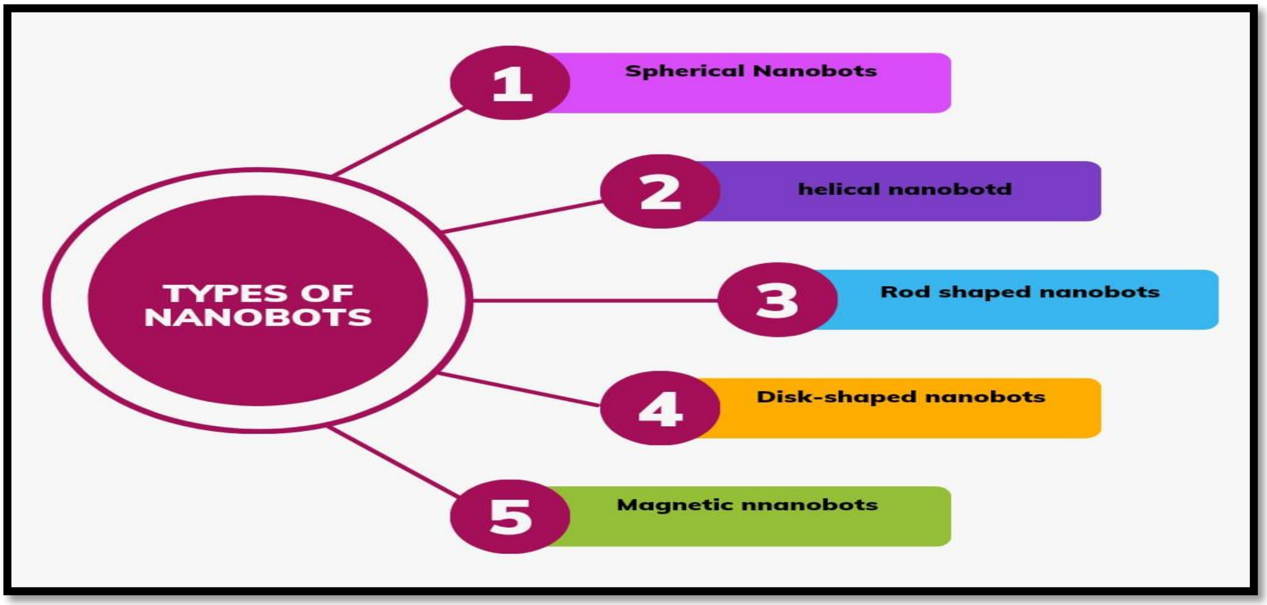

Fig. Types of Nanobots

B. Rod shape nanobots:

Rod-shaped nanobots are being used in cancer treatment because of their ability to avoid phagocytosis, circulate longer, and accumulate in tumors [12]

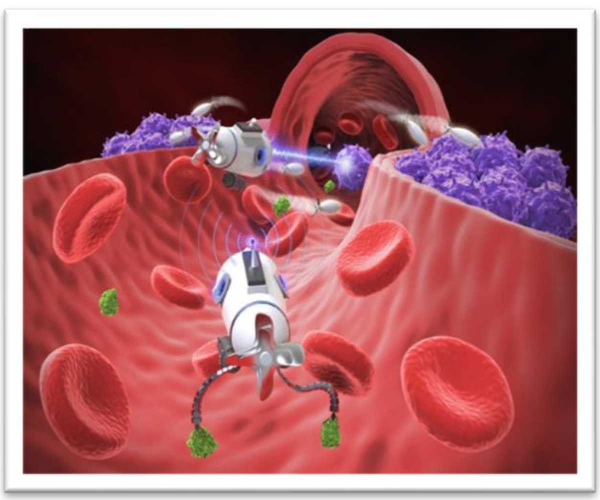

Fig 3.1. Rod shape nanobot

C. Helical nanobots:

Helical nanorobots feature a spiral structure and incorporate magnetic materials. The helical design gives the nanorobot its shape and enables movement along its spiral axis. These nanorobots have the potential to deliver anticancer medications directly to cancerous cells while sparing healthy cells. Additionally, they can assist in identifying tumor cells at the initial phases of cancer.

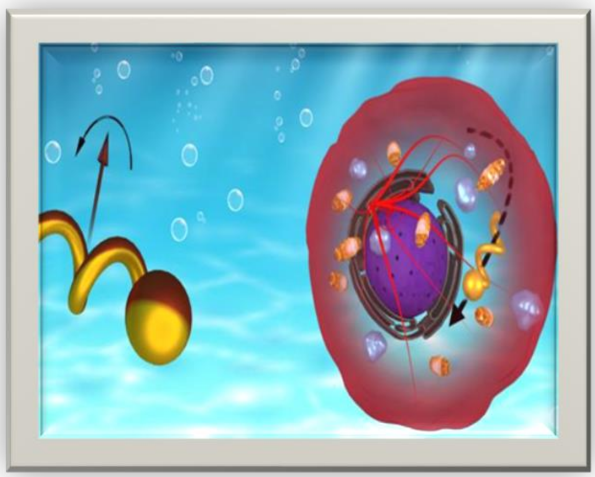

Fig: Helical nanobots

D. Spherical shape nanobots:

Spherical nanoparticles and nanorobots hold significant potential for cancer therapy due to their advantageous optical characteristics and biocompatibility. Spherical gold nanoparticles (AuNPs) possess the ability to transform light into heat, effectively targeting and destroying tumor cells.[13]

E. Disk shaped nanobots:

Disk-shaped magnetic particles can be heated by external magnetic fields to generate heat and damage cancer cells. Nanobots can transport anticancer medications into diseased cells without harming normal cells. The morphology of nanoparticles can be adjusted to enhance their circulation, facilitate tumor infiltration, and promote cellular uptake.[14]

II. MATERIALS USED IN NANOBOTS FOR CANCER TREATMENT:

To maximize their functionality, biocompatibility, and therapeutic efficacy, nanobots used in cancer treatment are usually constructed from a range of materials. Materials that are frequently utilized include: Biodegradable polymers are those that can safely break down inside the human body, such as polylactic acid (PLA) and polyethylene glycol ((PCL). Gold nanoparticles: Distinguished by their distinct optical characteristics, these particles can facilitate targeted drug delivery and improve imaging methods.[15] Silica nanoparticles: Frequently included into drug delivery systems, its porosity nature allows therapeutic substances to be encapsulated. [16] Carbon-Based Materials: This category features carbon nanotubes and graphene, which can improve drug delivery and display potential photothermal effects. [17] Liposomes are phospholipid-based spherical vesicles that have the ability to encapsulate medications, protecting them and improving their delivery to tumor locations [18] Magnetic Nanoparticles: These particles are used for targeted drug delivery and imaging, as they can be manipulated by external magnetic fields. Dendrimers: Highly branched synthetic macromolecules that can transport drugs and target specific cells. Hydrogels: These are water-swollen networks capable of encapsulating drugs and releasing them in a controlled manner.[19] These materials can be customized to exhibit specific characteristics, such as size, surface charge, and functionalization, to improve targeting efficiency and reduce side effects in cancer treatment.

Current therapy of cancer:

Stem cell therapy:

Stem cell therapy involves the use of undifferentiated cells located in the bone marrow, which possess the ability to develop into various cell types within the body. This therapeutic approach is regarded as both safe and effective for treating cancer. However, the use of stem cells remains largely in clinical trials, as research continues to explore their potential in regenerating damaged tissue. Currently, mesenchymal stem cells are being used in trials focused on bone marrow delivery, as well as in studies involving adipose and connective tissues.

A. Pluripotent Stem Cells:

Embryonic stem cells (ESCs) are derived from the homogenous inner cell mass of the embryo and have the potential to differentiate into almost all cell types except those that form the placenta. Yamanaka's breakthrough discovery in 2006, which demonstrated the ability to generate pluripotent stem cells (iPSCs) from human cells outside the body, marked a major advance in the field of cell biology. To avoid the ethical issues associated with embryo manipulation, iPSCs are often co-cultured with ES cells.Currently, hematopoietic embryonic stem cells (HESCs) and iPSCs are used to enhance effector T cell and natural killer (NK) cell activity and promote antibody production.

B. Adult stem cells:

Adult stem cells (ASCs) used in cancer therapy mainly consist of hematopoietic stem cells (HSCs), mesenchymal stem cells (MSCs), and neural stem cells (NSCs). The U.S. Food and Drug Administration (FDA) has approved the use of umbilical cord blood-derived hematopoietic stem cells for the treatment of multiple myeloma and leukemia. Mesenchymal stem cells are present in various tissues and organs and play a vital role in the repair and regeneration of cells such as bone cells, adipocytes, chondrocytes, etc. The unique biological properties of MSCs may serve as a complementary approach to other cancer treatments.

C. Cancer stem cells:

Cancer stem cells (CSCs) arise from epigenetic modifications of normal stem cells or progenitor cells. Their involvement in cancer treatment covers aspects such as tumor growth, metastasis, and recurrence, indicating their potential as a therapeutic target. Stem cells play various roles in tumor treatment. The rehoming process involves the rapid migration of hematopoietic stem cells (HSCs) to stem cell-rich areas of the bone marrow, followed by engraftment and subsequent generation of specialized cells. This mechanism depends on the interaction of stem cell receptors with endothelial cells. Another important mechanism is the tumor tropism effect, which recruits mesenchymal stem cells to the tumor microenvironment (TM). This interaction promotes the development of tumor stroma through differentiation processes.[20]

D. Working a principle of nanobots:

The nanorobot circulates in the bloodstream or diffuses into tissues. The targeting mechanism directs the nanorobot to the cancer cells. The navigation mechanism directs the nanobot to the desired location. The control system initiates the release or activation of the payload. The cancer cells are destroyed or eliminated. Integrating these capabilities allows nanorobots to improve the precision and efficacy of cancer treatments, and thus open a potential path to better outcomes with fewer side effects. Some of these issues need to be addressed, such as biocompatibility, scalability, and precise navigation in the human body [21]

- Step wise working of nanobots in cancer treatment shown in following flow chart:

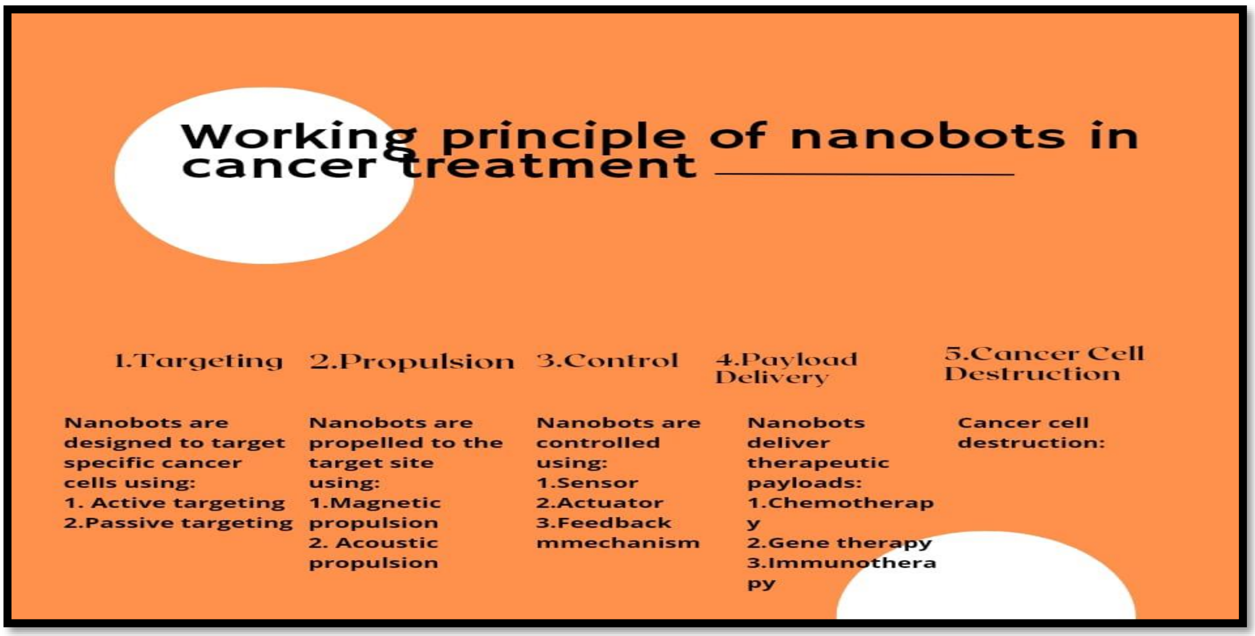

Table: Working principle of nanobots

III. CHALLENGES

Biocompatibility and toxicity: The metals, polymers, and synthetic materials used in the manufacture of nanobots can trigger immune responses and toxicity. Therefore, long-term safety and side effects are serious concerns.[22]

Efficient delivery: Delivering nanobots to tumors that are deep-seated or in inaccessible areas is also difficult. Obstacles such as the human body\'s immune system, the vascular system, and dense tumor microenvironments make it virtually impossible to deliver the minuscule nanobots with perfect efficiency.[23]

Control and Guidance: Control and guidance of nanobots within the human body would be a long-term challenge. As yet, we have only preliminary success in using magnetic fields or chemical gradients, which is still far from true real-time control within a dynamic human body.

Clearance and Persistence: After a nanobot has achieved its assigned task, it must be cleared out of the body. Such nanobots must be designed such that once they have completed their mission, either they biodegrade safely or are actively removed to avoid accumulation and long-term effects.

Production and Scalability: Mass production of nanorobots for clinical use remains a logistical challenge. The goal of producing nanorobots in sufficient quantities and with the necessary precision and reproducibility has not yet been achieved, especially at large scale for clinical use. Cost: Nanobots are very expensive to develop, test, and manufacture. Costs can be reduced without compromising their effectiveness and safety, and most importantly, their adoption in resource-poor settings.[24]

IV. FUTURE DIRECTION OF NANOBOTS

Advanced targeting method: Research focuses on the development of targeting mechanisms to improve treatment accuracy. One of these mechanisms is the use of ligands selectively binding to the bio marker of the cancer.

Multifunctional nanobots: In the future there may be nanobots that combine gene therapy, immunotherapy and chemotherapy for the delivery of numerous therapeutic molecules at the same time.

Real-time monitoring: By including biosensors or imaging technologies in nanorobots, the efficacy of therapy and tumor response can be monitored in real-time.

Personalized medicine: Nanorobotic therapies can be tailored to each patient's unique tumor profile to increase efficacy and minimize adverse effects.

Combined treatment: For example, searching for applying nanobot in collaboration with immunotherapy or radiation therapy may improve global treatment results.

Ethical and regulatory frameworks: As nanobot technology moves closer to clinical application, it will be essential to establish explicit ethical principles and regulations.

Clinical trials: Additional funding will be needed for clinical trials to evaluate the safety and efficacy of nanorobot therapies in various types of cancer.[25]

A. Application of nanobots in cancer treatment:

Nanorobots designed with enhanced detection capabilities could increase the speed of cancer diagnosis. The nanobots will respond to acoustic signals and receive programming instructions via external sound waves, as well as transmit the data they have accumulated. With specific programming to detect different levels of cancer biomarkers such as E-cadherins and beta-catenin, therapy can be delivered in both primary and metastatic stages of cancer. The advantage of nanorobots is that they produce targeted treatment. Nanotechnology for cancer biomarker detection. Protein detector. Circulating tumor DNA detection. MicroRNA detection. Detection of DNA methylation. Detection of extracellular vesicles. Detection of cell surface protein.mRNA based detection.[26]

Following are the application of nanobots in cancer treatment shown in flow chart:

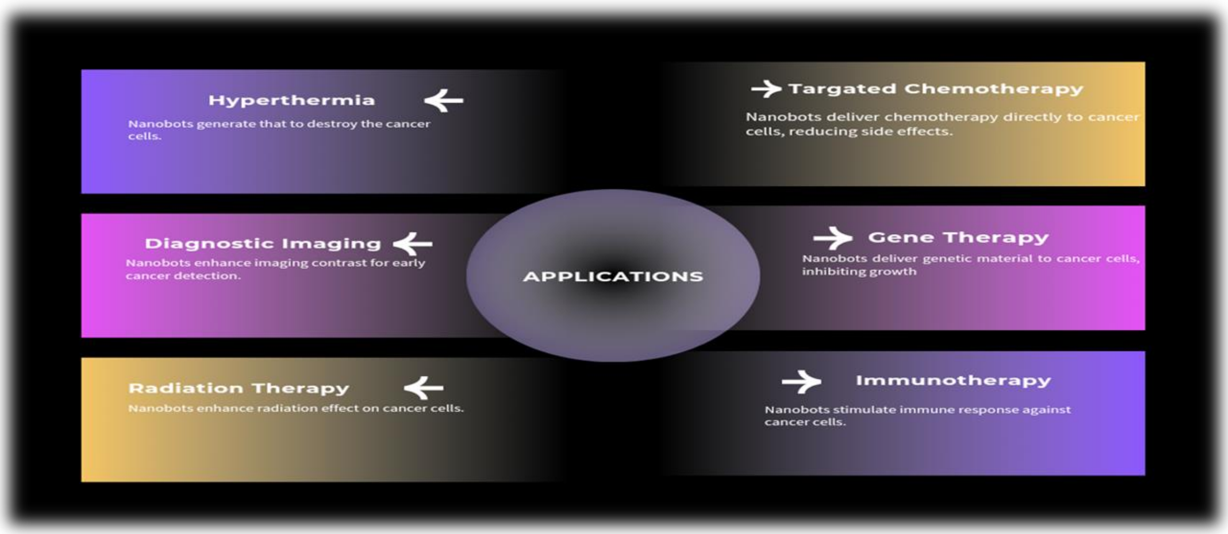

Fig. Application of Nanobots

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