

Nanorobots used in cancer treatment

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Abstract

Cancer, being one of the most violent diseases of the 21st century, is nothing new. The inability of traditional treatments to target cancer cells only without damaging the healthy tissue is the major cause of numerous side effects, such as nausea, hair loss, or fatigue, that are a result of this care. This review aims to analyze Nanorobots, their roles, and usage in cancer treatment. Nanorobots are microscopic devices designed to perform tasks at the nanoscale, are a promising solution. Their intricate design and functionality have created diverse applications, ranging from drug delivery systems to targeted therapy. These devices ensure accurate targeting of cancerous cells while avoiding damage to healthy ones. Compared to traditional treatment methods, nanorobot-based care boasts greater specificity, long-term effects, and reduced side effects. Even though challenges and issues, such as technical obstacles, safety concerns, and resource constraints, exist, these machines hold extensive promises to be the new standard in cancer care.

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1. Introduction

Today, cancer remains one of the most daunting challenges in medicine, with the traditional methods of treatment usually causing significant side effects, resulting from the inability to distinguish cancerous cells from healthy ones as well as a substantial risk of metastasis and relapse [1]. The estimated number of cancer patients in 2025 alone in the US is 2,041,910. Out of this large number, 618,120 people are expected to die from this disease [2]. Today, there are more types of cancer than one can count, with the most common ones being breast and prostate cancer, lung and bronchus cancer, melanoma, etc. [3]. These complications and daunting numbers point to the urgency of the new and innovative treatment options. Nanorobotics, microscopic devices designed to perform tasks at the nanoscale, one billionth of a meter, offer an optimistic solution [4]. By leveraging nanotechnology, these miniature devices have the potential to selectively target tumor sites and deliver various payloads, such as genes or drugs, through the circulating system of the body, all while avoiding damage to healthy tissue. Even with all the potential these devices hold challenges regarding their application as a standard cancer treatment. These issues must be addressed, from biocompatibility to funding and resources, before any real progress can be made.

In the past few decades, researchers and scientists have been trying to develop practical nanobots, such as sensors or data transmission, to offer alternative therapies that would eliminate all the by-products of traditional treatments mentioned previously, to aid in making cancer a more manageable disease [5]. Despite these

challenges, nanobots offer an optimistic and promising solution for cancer treatment with minimal complications and side effects.

2. Nanorobots: background and design

Nanorobotics represents a relatively young area of nanotechnology whose main specialty is the treatment and protection of living beings, humans in particular, from various pathogens of today. These nanodevices are man-made machines capable of traveling through the human body and communicating with cells at a molecular level [6]. With their sizes close to those of cells and organelles, ranging between 0.5 and 3 microns, they are equipped to perform assigned tasks with remarkable precision of 1-100nm [7]. Their miniature size gives them the ability to maneuver through even the narrowest parts of the human body. Combining these artificial machines with microorganisms capable of movement is the main driving force, specifically for nanorobots in biohybrid systems. Ultimately, designing these machines requires a lot of carefully thought-out components, the scale being one of the most important ones. As mentioned previously, the ideal size of nanorobots should be within the range of 0.5-3 microns [8]. This size allows them to move through the body with ease, and if these dimensions are not followed, further complications and issues might arise. Their exterior is primarily composed of a passive diamond shell that offers nanorobots much-needed immunity against potential charges [8]. Diamond is chosen as the main component of the shell, mostly because of its strength, inertness, and biocompatibility. Diamonds are the hardest known natural material, resistant to any wear and tear, and essential for nanobots and their navigation through complex surroundings [8]. Furthermore, diamond is extremely unreactive, meaning that it will not easily bind to other chemicals or be degraded by acids or bases [9]. Additionally, its biocompatibility and generally good tolerance of the body do not trigger the immune system or cause inflammation, allowing nanobots to interact with cells and tissues [9]. Overall, nanorobots are created based on their designated usage, implementing various technologies including microprocessors, payload, sensors, together with control systems, and actuators [10]. These technologies are precisely what enable the working systems in nanobots. The entire work of the nanobot is governed by microprocessors [8]. Integrating microprocessors in the build of the nanomachine gives it the ability to collect necessary data, and sense conditions of its surroundings, including pH or temperature, as well as enabling it to move, manipulate, and interact with the environment [11]. Payload, another crucial component of the nanobot, serves as the storage of drugs, as well as the release mechanism for when the nanorobot reaches the designated location. Sensors are there to recognize the chemicals in the body, guiding the robot to the proper location [8]. The presence of a specific type of molecule or material, as well as the unique signal, could be detected by the sensors. Nanobots could have antibodies attached to them that would specifically bind to overexpressed molecules or proteins on cancer cells [5]. Another exciting possibility is the ability to detect a difference in pH value between healthy and cancerous tissue. Tumor cells are recognized by their acidic microenvironment [12]. Once the drop in pH is detected, nanorobots could be programmed to release their payload to attack only cancer cells [12]. The focus could also be shifted to the outside environment, where nanorobots would be equipped with light sensors, which would open the doors for external control and the release of drugs and movement to specific areas of the body [4]. Once the information is picked up by those sensors, the next step is transmitted to control systems, which work hand in hand with the sensors. These control systems could be designed to use said information and act accordingly by implementing protocols designed specifically for the nanobot in usage [10]. The hopes for the control system are vast. For instance, biological signal processing is a cellular communication control system that could interact with the major pathways within the body, which would give access to nanobots to interact with their environment and detect any possible change [8]. Artificial neural networks would work on a similar principle as the human brain [13]. These control systems would be able to learn from their medium and adjust accordingly, thus improving efficiency and targeting [8]. Actuators have the potential to perform numerous actions such as movement, release of drugs into the human body, or even the manipulation of structures and materials [10]. One of those potentials lies in the drug delivery system (DDS), where microscopic channels and pumps could be used to accurately govern the flow and release of certain drugs, within the nanobot built, directly

into the cancerous environment [14]. To be able to perform these tasks, nanorobots must be capable of identifying their surroundings and acting according to the needs of the system they are designed for.

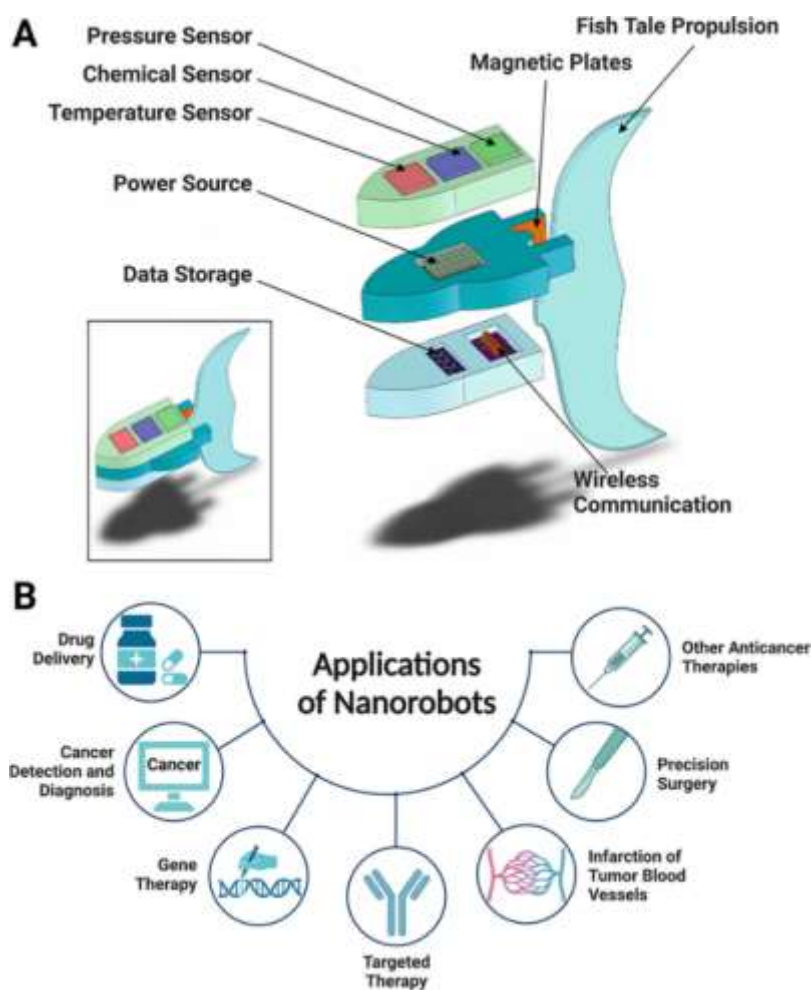


Figure 1 General design of nanorobots and their application [5]

2.1. Types of nanobots

Generally, scientists have divided nanobots based on their application in medicine to pharyocytes, respiocytes, clottocytes, and microbivores. Classified under the medical nanobots spectrum, pharyocytes are miniature nanobots, with sizes ranging between 100 and 1000 nanometers, able to carry up to $1 \mu\text{m}^3$ of a designated drug [15]. These machines utilize mechanical systems, such as sorting pumps, to effectively deliver drugs. Equipped with molecular markers or chemotactic sensors, accurate targeting of harmful cells in the body is ensured. To power their system, pharyocytes use glucose or oxygen extracted directly from the bloodstream. Once these machines have completed their mission, they can safely be removed from the body through the process of centrifuge apheresis [15]. This technique uses a centrifuge to separate blood components, allowing the removal of pharyocyte from the body.

Respiocyte is a spherical $1 \mu\text{m}$ diamondoid synthetic red blood cell, equipped with a reversible molecular-selective pump. This pump would be responsible for effectively loading and unloading the oxygen molecules into the device. The ability to give 236 more oxygen to the tissue per unit of blood than regular red blood cells (RBC) is a major advantage of this machine. To give that much more oxygen, these devices are constructed from 18 billion atoms, organized in a diamond pressure tank. These tanks will receive signals from the outside environment when oxygen needs to be discharged, and carbon dioxide unloaded [16]. Clottocytes, or in other words, artificial platelets, are another potential form of nanobots. These machines would have the ability to speed up the process of hemostasis. Hemostasis is a process of stopping bleeding once the vessels have been

damaged [17]. Once the bleeding begins, platelets rush to the site of injury, where they aggregate, forming a clot and stopping the bleeding. The hope for clottocytes is to act similarly, accelerating clotting and reducing blood loss overall.

Microbivores function as biological phagocytic defenses, whether naturally occurring or induced by antibiotics, up to 1000 times faster than biological phagocytes [15]. They are spherical devices with a diameter of 3.4 μm in diameter, composed of carefully organized atoms. Overall, these machines would be able to use the power of 200 pW to digest the trapped microbes, much faster than the macrophage agent [18].

These are just some of the main types of nanobots used throughout the medical field, from delivering oxygen to accelerating the blood clotting process and supporting the immune system. For additional context, Table 1 shows some of the most common types of nanobots, their function, and applications. Additionally, it is important to mention that all of these nanobots are in development phases and have not made their appearance in practice.

Table 1 Main types of nanobots, their function, and application

Type of Nanobot	Function	Application	References
Pharmacytes	Deliver drugs directly to cancerous cells	Cancer treatment	[16]
Respirocytes	Deliver oxygen to the tissue	Treatment of anemia; hypoxia	[16]
Clottocytes	Expedite the blood clotting process, hemostasis	Control of bleeding after injury	[17]
Microbots	Execution of various surgical procedures	Minimally invasive surgery; target tissue repair	[16]
Microbivores	Elimination of pathogens and bacteria	Fighting infections; immune system support	[18]

3. Advantages of nanobots compared to traditional treatments

Traditional chemotherapeutic drugs work by eliminating rapidly developing cancer cells. Additionally, most anti-cancer medications have limited therapeutic boundaries, meaning that they cause damage and toxicity to normal stem cells found for instance in bone marrow, gastrointestinal tract (GIT), and hair follicles, leading to numerous side-effects such as lower production of white blood cells (WBC), inflammation of the GIT, as well as alopecia (hair loss) [1]. Some of the traditional cancer-managing medications include doxorubicin, preferred for treating various forms of cancer, including Hodgkin's disease [19]. Similarly, paclitaxel is a medication administered intravenously and used primarily for breast cancer treatment [20]. One of the limitations of traditional cancer regimens is their inability to exclusively attack cancer cells without damaging healthy ones. Consequences of the previously mentioned side effects include delaying the treatment, reduction of drug dosage, or even stopping the therapy altogether [21].

The ability of nanomachines to navigate through the body as bloodborne devices is important in effective cancer treatment [5]. By using them in this manner, nanobots can deliver drugs at a precise dosing regimen, allowing the chemical compounds to be maintained in the bloodstream for extended periods, resulting in the expected pharmacokinetic parameters of chemotherapy used in anti-cancer treatments. The usage nanorobots allows for smart medication administration and targeting of only cancerous cells, keeping the surrounding healthy cells safe from the toxicity of the drugs [14].

Furthermore, the pharmacokinetics of chemotherapy include absorption, metabolism, and excretion, in addition to required rest time, which enables the body to realign itself before the next treatment session [22]. Nanorobots allow for much faster detection and assessment, eliminating all the mentioned issues.

To provide a better overview of the advantages the nanorobot cancer treatment offers as opposed to traditional ones, Table 2 shows some of the main advantages.

Table 2. Traditional Cancer Treatment vs. Nanorobot Cancer Treatment

Feature	Traditional Treatment Options	Nanorobot Cancer Treatment	References
Specificity	Can damage healthy cells also	Cancerous cells only	[10]
Side Effects	Numerous side effects, including nausea, hair loss, fatigue, and risk of metastasis	Minimal side effects	[1]
Efficacy	Depending on the type of cancer	More effective	[15]
Invasive	Some less invasive options, such as surgery or radiation	Minimally invasive	[1]
Cost	Can be expensive	Potentially higher cost	[5]
Availability	Widely available	Not yet used	

4. Potential usage of nanobots in cancer treatment

Differentiation of cancerous cells from normal tissue can be a challenging task. While cancer cells often show chemical changes on their surface, which the immune system can use to target them, these changes are often subtle and vary from cancer type. Additionally, some cancer cells not only develop so fast that their changes cannot be monitored and controlled, but also change their genetic makeup, causing even more issues [4]

The challenges of identifying and treating cancer have led to a search for alternative approaches, such as nanobots. The past few years have shown the progression of nanorobots from a simple theory to practice [5]. Even though significant progress has been made, these nanomachines are still in the early stages of development, showing their application strictly in early clinical trials. However, the potential these machines hold is immense. Possibly one of the most promising areas where the usage of nanobots would leave the greatest impact is cancer treatment. Currently, researchers and scientists are developing methods and ways in which traditional methods of cancer management would be considered history, making nanorobots the new standard [5].

Considering the characteristics of nanorobots and their ability to maneuver through the body as bloodborne devices, these machines can help in the treatment process of complex diseases, such as cancer, especially in early detection and drug delivery [23]. Implementation of nanorobots as drug delivery systems could result in a timely dosage regimen, keeping the integrity and pharmacokinetic properties of anti-cancer drugs for a longer time in the bloodstream [10]. Furthermore, nanorobots with chemical nano biosensors could potentially be programmed to recognize different levels of proteins and cells in the body, therefore leading to efficient targeting of malicious cells, as well as previously mentioned drug delivery [5].

Moreover, by aiding tissue repair and regeneration, as well as immune system modulation, nanorobots hold the key to completely transforming regenerative medicine [5]. Minimally invasive surgeries and more accurate and selective interventions are another potential for nanorobot application, which could lead to reduced trauma and a much faster recovery time [24]. Additionally, one of the proposed ways in which nanobots should be introduced into the system is in the form of intravenous injections, for diagnostics, surgery, or desired therapy. By administering them to the patient in this manner, accurate therapy is ensured, and the rest of the tissue is safe.

As mentioned, multiple times already, these devices hold answers to tackling the complexities of current cancer treatments [5], and the overall health of the public.

5. Challenges and limitations

While it is true that nanobots hold great hope in finally ending major issues with current cancer treatment, numerous issues and complications need to be addressed before they can be adopted into practice and used as the standard form of cancer management [10]. Developing and handling nanorobots for cancer treatment requires overcoming numerous technical struggles, including developing nanoscale components, monitoring and controlling their movement through the body, and maintaining their overall stability [5]. Additionally, due to the complexity of magnetic fields in narrow spaces of the body and interference of other electromagnetic waves, accurate control of magnetic nanorobots using these externally applied magnetic fields is difficult and could potentially lead to improper tumor site targeting and further issues and injuries to human tissues and/or organs [25]. The biological environment of the human body and its influence on the speed and precision of nanobots also need to be considered. Numerous proteins, different cell types, and their interaction with unknown particles can lead to issues in movement or even the complete removal of the machine from the system [26]. Safety concerns are another common challenge. Faulty nanobots could not only harm the patient but also lead to more issues and complications, compromising the treatment process further [5]. To get ahead of these concerns through clinical and preclinical trials is crucial, thereby tackling not only safety issues, but also the biocompatibility, pharmacokinetics, and pharmacodynamics of these machines, as well [5].

The lack of comprehensive rules that regulate the development and usage of nanobots could be what holds institutions back from fully adopting these machines in practice. Since the focus is on application in cancer treatment, appropriate frameworks that would successfully address these problems, while at the same time supporting innovation and the protection of everyone involved, are required [25]. Money and resources play a crucial role. Nanorobotics and its adaptation in clinical practice are expensive ventures, demanding sizable funding and resources, including human expertise and equipment [5]. Obtaining these resources and funding is cardinal to advancing the area of nanorobotics further.

These are just some of the limitations and challenges that the field of nanorobotics is currently facing, and that are putting a hold on their adaptation to practice and cancer treatment overall. Facing all these complications could be a step closer to making nanorobots a new standard in treatment.

6. Conclusion

The potential that nanorobots have to reform the treatment of cancer cannot be denied. With their unparalleled precision in drug delivery systems and targeting cancerous cells exclusively, the power they hold to eliminate not only all of the issues of traditional chemotherapy but also other health concerns as well, including oxygen loading, blood clotting acceleration, etc., is immense. It is due to their miniature build and impressive nanotechnology that these devices offer another perspective in standard patient care. Despite all their advantages, various complexities exist that need addressing. Technical obstacles, biocompatibility, resources, and funding are just some of the issues that are keeping nanorobots from becoming the new standard in treatment. All issues aside, nanobots hold the key to making cancer far more manageable and curable.

Declaration of Competing Interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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