INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Nanorobots-The Future of Medicine

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ARTICLE INFO

Published: 05 Feb. 2025

Keywords:

Nanorobots, Nanomedicine, Targeted Drug Delivery, Applications.

DOI:

10.5281/zenodo.14807981

ABSTRACT

The science of robotics is expanding quickly, and a new avenue for human health treatment has been made possible by the creative idea of shrinking robots to nanoscale size. A growing number of researchers are focusing on nanorobots in an effort to investigate all of their possible medical uses. This article focuses on the basic design architecture of the nanorobots, its mechanism of working, approaches and their wide applications in the medical field. Drugs could be carried and delivered by nanorobots into cells with defects. These nanorobots have the ability to reverse the aging process, change our physiological capacities, clean blood vessels and airways, and heal tissues. Moreover, in future nanorobots will have wide applications in health care sector.

INTRODUCTION

Nanotechnology is a part of science and technology whose main aim is to control matter on atomic, molecular and cellular scale. These nano-machines have wide applications in the medical field. Richard Feynman, the laureate of the 1959 Nobel Prize, is credited with giving the speech "There's Plenty of Room at the Bottom," which is frequently cited as the origin of nanotechnology. In this speech, Feynman explores the potential (i.e., in theory) of what is currently called nanotechnology and how further research and development could lead to a vast array of technological uses. In 1980s, with the discovery of carbon nanotubes by Sumio Iijima, Richard Smalley has expanded his vision to include what he sees as the next great connectivity for incredibly compact electronics. The manipulation of elements to create a unique and hopefully helpful structure is now referred to as nanotechnology. Nanotechnology is defined as "the processing of, separation, consolidation, and deformation of materials by atom or molecule" by Professor Norio Taniguchi in 1974. Dr. Eric Drexler writes multiple scholarly articles in the 1980s endorsing devices and phenomena at the nanoscale. In 1986, Dr. Eric Drexler's book ‘Engines of Creation: The Coming Era of Nanotechnology’ is published, which is the first book on nanotechnology. He visualizes nanorobots as self-replicating

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

nanorobots. In 1981, IBM Zurich's Gerd Binnig and Heinrich Rohrer created the scanning tunneling microscope (STM)- utilized for atomic-level surface imaging and property identification (e.g., energy). The discovery of fullerenes, or molecules made completely of carbon, occurred in 1985. They are widely used in nanotechnology, electronics, and materials research. In 1991, carbon nanotubes, or cylindrical fullerenes, were directly discovered as a byproduct of fullerenes– possess exceptional electrical qualities, a high tensile strength, and effective heat conductivity. Transistors and super capacitors, for example, are perfect circuit components due to their electrical characteristics. Carbon nanotubes have recently been employed in chemical and biomedical engineering studies as a drug delivery system for the body. Atomic force microscope (AFM) invention, 1991, isa cutting-edge instrument for measuring, visualizing, and working with materials at the nanoscale. It feels the surface using a mechanical probe to carry out its operations. It's referred to be a nanorobot since it can precisely interact with materials at the nanoscale. In 2000,it was decided to coordinate federal research and development in nanotechnology by founding the United States National Nanotechnology Initiative, is a significant research endeavor in the field of nanotechnology. In2000, Nanofactory Collaboration is established, putting together a research plan to construct a nanofactory that can produce nanorobots for use in medicine. Development is now underway on DNA machines, often known as nucleic acid robots which reacts to specific inputs by executing motions that resemble those of a mechanical device, such as switching [1,2,3]. According to one definition, nanotechnology is the study of atom- and molecule-level phenomena with practical applications. Nanotechnology is the field of technical advancements that occur on a nanoscale, often between 0.1 and 100 nm. One billionth of a meter is equal to one nanometer (1 nm = 10^{-9} m). The diameter of a hydrogen atom is approximately0.1 NM from an atomic perspective. Ten hydrogen atoms arranged side by side would therefore be roughly 1 nm across. Since nanotechnology involves many different technological domains, including chemistry, physics, molecular biology, material science, computer science, and engineering, it is inherently an interdisciplinary field. Nanorobotics is a burgeoning field of nanotechnology. Nanorobots are extremely small size machines. Their size ranges from 1-100nm.Nanorobots are so tiny that they can easily travel in the hard-to-reach areas of our body, thus are useful for diagnosis and treatment purposes. Moreover, these can also be widely used as targeted drug delivery system especially for diseases like- cancer, arteriosclerosis and for gene therapy. Nanorobots enhance the effectiveness of the therapeutic agent in the targeted location and promote a quick recovery. They are fantastic instrument for modern medicine. We can imagine a time where we could infuse billions of these nanorobots inside the body, causing them to float around. Drugs could be transported and delivered into damaged cells using nanorobots. These tiny robots will have the capacity to restore organs, clear airways and blood arteries, alter human physiological processes, and possibly even slow down the aging process. As a new tool in medicine, nanotechnology, particularly in the treatment of diabetes, arteriosclerosis, cancer, gene therapy, and dentistry, has demonstrated how advances in new manufacturing technologies are enabling creative work that could lead to the development and efficient use of nanorobots for biomedical issues [1,2,3]. One of the many applications of nanotechnology is the development of bioresponsive, nanoscale devices that can identify conditions and then administer medication to the desired place. The field of nanotechnology is one that is altering how medical science is perceived.

Thesynthesis, characterization, and use of nanoparticles in scientific domains are all included in nanotechnology. They have special visual, biological, and electrical qualities. Numerous physical and chemical synthesis techniques have been documented in the literature. Because biological synthesis is environmentally benign, enzymes, bacteria, fungi, algae, and plant extracts have all been used.Onboard sensors, power supply, motors, manipulators, and molecular computers are all included in the designs of nanorobots.The potential uses of nanorobots in medicine are immense, ranging from curing sickness to delaying the aging process. Another option for industrial use is the nano robot. They will offer individualized, currently unavailable therapies with greater efficacy and fewer negative effects. They will offer surgery with immediate diagnostic input, imaging agents that function as medications, and combined action pharmaceuticals sold with diagnostics. The development of molecular nanotechnology will greatly increase future medical treatments' efficacy, comfort, and speed while also drastically lowering their risk, expense, and invasiveness. Nanorobotics may seem like science fiction right now, but it has the potential to completely change healthcare and the way diseases are treated in the future. It creates new avenues for extensive, copious investigation[4,5]. Nanorobots are fantastic instrument for modern medicine. We can imagine a time where you could infuse your body with billions of these nanorobots, causing them to float around. Drugs could be transported and delivered into damaged cells using nanorobots. These tiny robots will have the capacity to restore organs, clear airways and blood arteries, alter human physiological processes, and possibly even slow down the aging process. As a new tool in medicine, nanotechnology, particularly in the treatment of diabetes, arteriosclerosis, cancer, gene therapy, and dentistry, has demonstrated how advances in new manufacturing technologies are enabling creative work that could lead to the development and efficient use of nanorobots for biomedical issues[5, 6]. The use of nanotechnology will transform more significantly than previous advancements in health care and human existence. As so, they will expand the scope of product development and marketing to transform the industry relationships between the biotech, pharmaceutical, diagnostic, and healthcare sectors.Nanorobotics opens up vast areas for research work. It has a great chance to treat disease and transform healthcare in future[4,5,6].

Nanomedicine:

Nanomedicine is a branch of medicine that utilizes nanotechnology for the diagnosis,treatment, and monitoring of disease. It involves the design and application of nanoscale materials and devices to target specific cells or tissues, offering potential improvements in drug delivery, imaging, and overall therapeutic effectiveness. Using a molar device and microscopic data on human physiology, ‘Nanomedicine’ is one of the most promising uses of therapeutic nanotechnology. A tiny engine called ‘nanorobotics’ is designed to continuously and precisely perform certain tasks at nanoscale level. Human will use these nanodevices to fight off infections and preserve their health. Biologically motivated nanorobots and fluorescence combine to create real-time imaging. When used in conjunction with targeting ligands, nanorobots offer an effective way to deliver the therapeutic substance, partially realizing the idea of a ‘magic bullet’. Enzymatic nanolithography is essential to the target delivery of nanorobotics. Nanorobotics can reduce the problems encountered with complex surgery and expand the range of a medical practitioner[7,8].

Advantages of Nanorobots:

- Can be used as targeted drug delivery system- they work only on specific site [9];

- Help in performing painless and non-invasive surgeries [9];
- It has no or less side effect[9, 10];
- Can reach remote areas in human body which is not possible through surgeries [10];
- They can break up the blood clots[11];
- Better accuracy[11, 12];
- It has high durability [12];
- It is environment-friendly [12];
- It is useful for monitoring, diagnosing and fighting sickness[13];
- It can stimulate body systems and monitor neuroelectric signals[13].

Disadvantages of Nanorobots:

- They are very costly[9];
- It very complicated to design nanorobots[10];
- It is very hard to interface and control them externally[9,10];
- Its functioning should be accurate otherwise it can cause harmful effect in our body[11];
- Nanorobots pose a risk in the field of terrorism[11];
- Electrical nanorobots are vulnerable to external electric interference, such asradiofrequency or electric fields, and stray fields from other *in vivo* electrical devices[12];
- Electrical system can produce stray fields that can activate bioelectric-based molecular recognition systems in biology[12,13].

Components of Nanorobots

For the proper functioning of nanorobots, the following key components are required-

- **Payload**- it is a void section within the nanorobots that hold small amount of drug or medicine. it is one of the main components of nanorobots, that helps it to release the drug to the site of infection or injury [14,15].
- **Microcamera**- the nanorobots can include a miniature camera. the camera is useful for diagnosis purpose and also the operator can guide the nanorobot externally [14,15].
- **Electrodes**- electrodes installed on the nanorobot could form the battery using the electrolytes in the blood. they can also kill the cancer cells through heating, by generating electric current [14,15].
- **Lasers**- harmful materials present inside our body like- arterial plaque, blood clots or cancer cells can be burnt by these lasers [16,17].
- **Sensors**- they help the nanorobots to reach their desired target. chemical, biological, optical, magnetic and thermal sensors have been tested in nanorobots [16,17].
- **Swimming tail**- nanorobots will need an artificial swimming tail as means of propulsion in order to enter the body because they travel against the blood flow [17,18].

Types of Nanorobots

- **Pharmacyte:** it's a 1-2µm medical nanorobot that can hold up to 1µm of a specific medicine in its tanks. for sorting pumps, mechanical methods are used to control them [19,20].
- **Respirocyte:** it is a nanorobot that functions as an artificial red blood cell and is an artificial oxygen carrier. It is generated by the body's own serum glucose [19,20].
- **Microbivores**: it is an oblate spheroidal device with a major axis diameter of 3.4µm and a minor axis diameter of 2.0µm that is intended for use in nanomedical applications [21,22].
- **Clottocytes:** are a special kind of nanorobot thatacts as an 'artificial platelet' and have the capacity to provide "instant"hemostasis (less than 1 second). It is known that platelets are roughly spheroidal blood cells with no nucleus that have a diameter of about 2 µm. They work similar to the platelets present in our blood[21,22].
- **Chromallocyte:** by replacing whole chromosomes in individual cells, chromallocytes can reverse the effects of aging-causing genetic diseases and other cumulative harm to our DNA[23,24].

- **Helices:** several robots with screw-like helix tails for locomotion have been created; these robots frequently resemble biological structures like bacterial flagella. The majority of them, like the mofbots and the previously described magnetosperm, are better categorized as micro-sized robots [23,24].
- **Nanorods:** these are usually cylindrical rods containing various metal segments, though they can also be made in other shapes. Nanorods are cylindrical rods containing various metal segments, yet they can also be utilized in other shapes for the same function [24,25].
- **DNA nanorobots:** these nanoscale machines are built utilizing DNA, which is composed of deoxyribonucleic acid molecules. they can occasionally be modeled after DNA origami, which is the folding of DNA molecules into shapes and patterns[24,25].

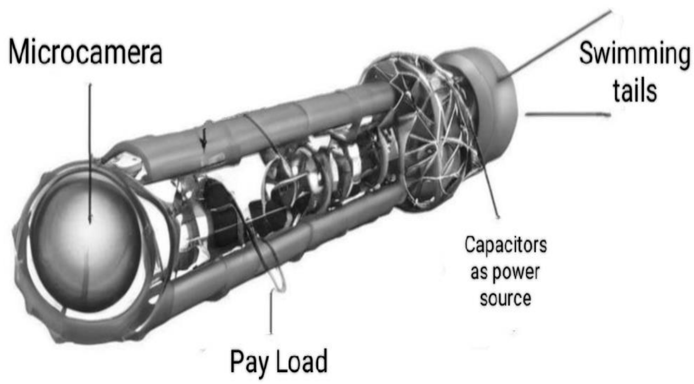

Figure1: Basic components of Nanorobots

Mechanism of Working:

The basis for nanorobotics is the use of nanoscale robots, or nanorobots. The way that nanorobots are made and function varies based on what purpose they are intended for. Nanoscale sensors, control systems, and actuators are just a few examples of the technologies that nanorobots would typically use to function. The control system could receive information from the sensors in nanorobots that identify particular signals or circumstances, such as the existence of a particular kind of material or molecule. The control system could then utilize this data to determine what course of action is best for the nanorobot. The actuators on the nanorobots could be used for a variety of tasks, such as moving, releasing medication into the body, or manipulating materials and structures[26]. A simplified overview of their working is as follows:

1. **Power source**- nanorobots need an energy source. This could be provided externally (e.g., through magnetic fields) or internally (e.g., through chemical reactions or harvested energy from the environment)[26,27].
2. **Propulsion**- nanorobots require a means of movement. Propulsion systems, such as tiny motors or flagella-like structures, enable them to navigate through biological environments or other mediums[26,27].
3. **Sensors**- nanorobots are equipped with sensors to detect specific signals or conditions. These sensors could include chemical sensors, imaging devices, or other means of perceiving the surrounding environment[28,29].
4. **Actuators**- to perform tasks, nanorobots use actuators- components that allow controlled movement or manipulation. These could include mechanisms for gripping, releasing substances, or even carrying out precise surgical actions[28,29].
5. **Communication**- nanorobots may communicate with each other or with external devices. This communication enables

coordination among multiple nanorobots or the transmission of data for analysis[30,31,32].

6. **Control systems-** advanced control systems govern the nanorobots actions. These control systems can be pre-programmed or responsive to external stimuli. They ensure that the nanorobots perform tasks accurately and adapt to changing conditions[30,31,32].

Approaches in Nanorobotics:

- **Biochip** – the combined use of novel biomaterials, photolithography, and nanoelectronics offers a potential method for producing nanorobots for widespread medical use, including drug delivery, surgical instruments and diagnosis. Biochips comprise biomolecules fixed in microchannels, microcells, or an array of beads or sensors, in addition to immobilized biomolecules spatially addressed on planar surfaces. Biochips are now commercially viable as they can be implanted inside the body to transfer data dynamically and track any changes in biology *in vivo*[33].
- **Nubots**– these are organic molecular machines, or ‘nucleic acid robots’ as the term ‘nubot’ suggests. Small molecules, proteins, and other DNA molecules can be used to activate DNA-based machines, and DNA structure can be used to create 2D and 3D nanomechanical systems. The drug delivery system of nubots uses their DNA structure as a carrier[33].
- **Bacteria based** –the utilization of biological microorganisms, such as the bacteria Escherichia coli, is suggested by this method. Hence, the model propels itself using a flagellum. Typically, this type of biological integrated device moves in response to electromagnetic fields[34].
- **Open Technology** – a proposal for the development of nanobiotech through open technology techniques has been submitted to the UN General Assembly in a document. The statement submitted to the UN states that a comparable strategy would benefit society as a whole and accelerate progress in the same manner as open source has recently expedited the development of computer systems[34].
- **Nanobearing and Nanogears** –molecular bearings are the most practical class of components to develop because of their straightforward construction and straightforward operation[34].
- **Biohybrids** – Bio-hybrid systems, an emerging field, integrate synthetic and biological structural features for applications in biomedical or robotics. Nanoscale components, such as proteins, DNA, or mechanical parts with nanostructures, make up bio-nanoelectromechanical systems (BioNEMS). The direct writing of nanoscale features is made possible by thiolene e-beam resist, which is then functionalized with biomolecules to provide a naturally reactive resist surface. Alternative methods employ a biodegradable substance affixed to magnetic particles to facilitate their guidance[33,34].
- **Virus-based** – It is possible to retrain retroviruses to bind to cells and take the place of DNA. They use a procedure known as reverse transcription to transfer genetic material within a vector. These devices are often the virus's Pol-Gag genes for the Capsid and Delivery systems. Retroviral gene therapy is the term for this technique, which uses viral vectors to re-engineer cellular DNA. Gene delivery techniques such as lentiviral, adenoviral, and retroviral have emerged as a manifestation of this strategy. Cats have been utilized as genetically modified organisms (GMOs) to express certain traits by introducing genes into the GMO[33, 34].

Application of Nanorobots:

Nanomedicine has recently witnessed a breakthrough in molecular nanotechnology. Disease treatments are becoming more accurate, efficient, and quick. They go through the body of a person with ease. A potential source of propulsion is oxygen and glucose. An essential characteristic of nanomedicines is their ability to target medication administration and facilitate early illness diagnostics. Because microscopic blood clots are difficult to cure with traditional operations, nanorobots are employed to break them apart[35,36].

1. **Drug Delivery System:**Small machines with a single purpose, nanobots are just a few nanometers broad. When it comes to administering drugs, they are quite useful. Substances travel the whole body to arrive to their intended location. The medication may be directed to a specific area using nanotechnology. In addition to lowering the likelihood of adverse effects, this would increase the drug's effectiveness.The fact that nanobots can regulate the amount and timing of medicine delivery is a huge benefit. The electrical pulse may be adjusted to manage this[37,38].
2. **Disease Diagnosis & Prevention:**In tissues and the bloodstream, medical nanorobots may carry out a wide range of diagnostic, testing, and monitoring tasks. The temperature, pressure, chemical composition, and immune system activity, among other vital indicators, may all be continually recorded and reported by these devices from all areas of the body[36].Microchips covered with human molecules have been successfully created by nano-biotech experts. The microchip generates an electrical pulse when the chemicals identify illness. Under the skin are inserted certain sensor nanobots that can identify illness symptoms. Additionally, blood sugar levels may be tracked using them. It is fat deposits that obstruct the blood arteries that trigger heart attacks. By using these, cardiac disorders can be avoided. These fat deposits can be removed by nanorobots[36].
3. **In Cancer Treatment:** The application of nanorobotics to cancer treatment is successful. As nanobots administer drugs with efficiency and targeting, they can reduce the negative effects of chemotherapy. When a patient's tumor cells are still developing, they can be found within their body using nanorobots equipped with chemical biosensors. To measure the strength of the E-cadherin signals, integrated nanosensors can be used. Once they arrive at the tumor, the three-micrometer-sized nanobots that contain the genetically altered salmonella bacteria deliver the medication.

   When attacking a tumor, the nanobot doesn't harm healthy cells. This stops the chemotherapy adverse effects from occurring for the patient.The critical elements of an effective cancer treatment plan without any negative side effects focuses on early cancer identification before metastasis has started and tailored medication delivery[36,39].
4. **In Surgery:** The vascular system or the tips of catheters inserted into different body cavities and veins could be used to introduce surgical nanorobots into the body. An on-site, semiautonomous surgeon within the human body could be performed by a surgical nanorobot that is programmed or directed by a human surgeon. Coded ultrasound signals are used to communicate with the supervising surgeon as it searches for pathology, diagnoses lesions, and corrects them by nanomanipulation. All of these functions are managed by an on-board computer. We are now investigating the earliest types of cellular nanosurgery[40].
5. **In Gene Therapy:**The molecular structures of proteins and DNA within cells can be

compared to desired or known reference structures by medical nanorobots, enabling them to easily treat hereditary disorders. Following that, any anomalies can be fixed or the needed changes can be made directly on the document. Chromosome replacement therapy may be superior to cyto-repair in certain circumstances[39].

6. **In Diagnosis &Treatment of Diabetes:**The proper amount of glucose in the blood is crucial for the diagnosis and management of diabetes as it keeps the human metabolism functioning in a healthy manner. The protein hSGLT3, which is inherently linked to glucose molecules, plays a crucial role in skeletal muscle and gastrointestinal cholinergic nerve activity, as well as in controlling the amount of extracellular glucose[36]. Patients with diabetes can use the hSGLT3 molecule to define their blood glucose levels.That this protein functions as a glucose sensor is perhaps its most intriguing feature. Complementary Metal Oxide semiconductor (CMOS) nano-bioelectronics are integrated into the simulated nanorobot prototype model[36]. The nanorobot has no problems sensing blood glucose levels, regardless of whether it is visible or invisible to immune responses. Because of its biocompatibility, the nanorobot remains safe from white blood cell attacks even in the face of an immune system response within the body. The integrated chemosensor that the nanorobot utilizes to monitor glucose involves modulating the activity of the hSGLT3 protein. The nanorobot can therefore efficiently ascertain if the patient requires an insulin injection or any other activity, such as taking any professionally prescribed prescription, thanks to its onboard chemical sensor[36]. They track the blood's glucose levels as they circulate through it alongside red blood cells. When using a medical nanorobot design, the patient's mobile phone may immediately get the important measured data via radio frequency signals. The cell phone is used by the nanorobot to sound an alarm if the glucose reaches a critical level [40].
7. **In Dentistry:** A new discipline known as "nanodentistry" is emerging as a result of the increased interest in the potential dental uses of nanotechnology. In order to increase tooth durability and reposition uneven teeth, nanorobots can desensitize teeth, produce mouth analgesia, and manipulate tissue [40].

   For significant tooth repair, nanodental treatments incorporate a variety of tissue engineering approaches. Biologically autologous entire replacement teeth with both mineral and cellular components are primarily manufactured and installed by nanorobotics, resulting in full dentition replacement treatment [40]. Sapphire, a nanostructured composite material, has been made possible via nanodentistry, and it improves the beauty and durability of teeth. Sapphire is relatively prone to acid damage, just like enamel. Sapphire is the greatest cosmetic substitute for traditional whitening sealants. Nanocomposites are a new type of restorative nanomaterial that can strengthen teeth [40].
8. **In Cell Repair &Lysis:** Using nanorobots to connect to white blood cells or inflammatory cells that are traveling to swollen tissues and aid in their healing process might be an intriguing application of these machines. Using a mobile cell-repair nanorobot, the cell repair mission can be completed by returning to the bloodstream and then removing the device from the body. The device can travel limited vascular surface travel into the capillary bed of the targeted tissue or organ, followed by extravasations, histonation, cytopenetration, and complete chromatin

replacement in the nucleus of one target cell[37].

9. **Act as Artificial Neurons:** Because they are made to work similarly to regular, everyday neurons, nanorobots can be used to replace every neuron in the human brain. From a functional standpoint, the nanotech neurons are equal. They serve the same functional purposes and are connected to the same synapses as the original neuron[38,39].
10. **As Artificial Phagocyte (Microbivore):**

The "digest and discharge" method is the principal means by which microbiological pathogens present in the human circulation are eliminated by microbivores, which are artificial mechanical phagocytes of tiny size. By employing the "digest and discharge" method, microbivores primarily eliminate microbiological infections that are present in human blood[36]. In contrast to the weeks or months required for antibiotic-assisted natural phagocytic defenses, intravenous (IV) microbivores might completely clear the most severe septicemic illnesses in hours or less. Since the pathogens are entirely broken down into innocuous simple sugars, monoresidue amino acids, mononucleotides, free fatty acids, and glycerol—the physiologically inert byproducts of the nanorobot—the danger of sepsis or septic shock is not increased by the nanorobots[36].

11. **As aArtificial Oxygen Carrier:** "Respirocyte" is the name of the imagined nanorobot that functions as an artificial mechanical red cell that floats throughout the bloodstream. A small pressure tank that can be filled with molecules of carbon dioxide (CO_2) and oxygen (O_2) is what the respirocyte essentially is. A controlled discharge of these gasses is possible from the small tank[38].

    The sorting rotors are instructed by the onboard computer to load the tanks with oxygen and discharge the CO_2 when the nanorobot passes through the lung capillaries, where O_2 partial pressure is high and CO_2 partial pressure is low. The sensor results are inverted when the gadget subsequently finds itself in the peripheral tissues that are oxygen-starved. The onboard computer directs the sorting rotors to emit O_2 and absorb CO_2 since the partial pressures of CO_2 and O_2 are comparatively high and low, respectively[38].

    With a capacity to give 236 times more oxygen per unit volume than a genuine red blood cell, respirocyte imitate the function of real hemoglobin-filled red blood cells[38].
12. **In Kidney Stone:**The bigger the stone, the more difficult it is to pass, and the discomfort can be extraordinary. Using a small laser, a nanorobot might dissolve kidney stones[41].
13. **In Cleaning Wounds:**The chance of infection might be reduced by using nanorobots to assist clear debris from wounds. In situations where it might be challenging to treat puncture wounds with more traditional techniques, they would be very helpful[38].

CONCLUSION:

Sensitive new diagnostics will be used in future healthcare to better identify individual risk. If the key diseases that burden the aging population the most—cancer, musculoskeletal disorders, diabetes, mental and neurodegenerative diseases, cardiovascular diseases, and viral infections—are treated initially, the greatest impact can be anticipated. Nanomedicine has the potential to improve follow-up care, therapy, and early diagnosis, increasing the effectiveness and affordability of healthcare. By utilizing the comprehensive knowledge of diseases at the molecular level, nanomedicine will also enable more individualized treatment for a wide range of illnesses

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HOW TO CITE: Dr. Paramita Dey*, Susmita Ghosh, Shreya Das, Nanorobots-The Future of Medicine, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 2, 291-302. https://doi.org/10.5281/zenodo.14807981