A REVIEW ON INNOVATION IN NANOTECHNOLOGY AND EXPLORING THE ETHICAL IMPLICATIONS OF NANOROBOTICS IN HEALTHCARE

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ABSTRACT

Nanorobotics is the technology of creating machines or robots at or close to the microscopic scale of a nanometer. These devices are ranging in size from 0.1-10 micrometers and constructed of nanoscale. Due to their small size and wide functional properties, nanorobots have created exceptional prospects in medical, biomedical and pharmaceutical applications. The names nanobots, nanoids, nanites or nanomites have also been used to describe these hypothetical devices. Nanorobots are capable of performing task like actuating, sensing, signalling, information processing and intelligence at the nanoscale.

The nanobots or nanoids[nanorobots] are constructed of the nanoscale or the molecular components. At this time, as no artificial non-biological nanorobots have been created so far, they remain the hypothetical concept. This articles focuses on history of nanorobots, composition of nanorobots, mechanism of nanorobots & applications of nanorobots.

Finally, we discuss the challenges and the potential research opportunities of the micro/nanorobots. In the future, it is expected that micro/nanorobots will become more sophisticated and capable of performing multiple medical functions and tasks. They will be implemented in vivo to assist medical doctors in diagnosing and treating diseases

KEYWORD: Nanotechnology, Nanorobots, Cancer therapy, Medical device.

INTRODUCTION

Nanorobotics encompasses the technology involved in the development of machines or robots that operate at or near the nanoscale, specifically at dimensions of approximately one nanometre (10^-9 metres). This field primarily pertains to the theoretical aspects of nanotechnology engineering, focusing on the design and construction of nanorobots. These nanorobots, also referred to as nanobots or nanoids, typically measure between 0.1 and 10 micrometres and are composed of nanoscale or molecular elements. As of now, no artificial non-biological nanorobots have been successfully created, rendering them a theoretical concept. An alternative definition describes a nanorobot as a device capable of precise interactions with nanoscale objects or capable of manipulation at the nanoscale level. Under this definition, even larger instruments, such as atomic force microscopes, can be classified as nanorobotic tools when they are adapted for nanomanipulation tasks. Additionally, robots at the macroscale or microrobots that can operate with nanoscale accuracy may also fall under the category of nanorobots. Nanobots, constructed from nanomaterials, are designed to perform specific tasks. Researchers are optimistic about the potential applications of nanobots in medicine, including the destruction of cancer cells, targeted drug delivery, and enhancement of vaccines. Furthermore, nanobots are utilized in scientific research as DNA probes, imaging agents for cells, and vehicles for targeted delivery to specific cell types.[1]

Richard Feynman noted that the concept of utilizing his theoretical micro-machines for medical purposes was initially proposed by his former graduate student and collaborator, Albert Hibbs, around 1959. Hibbs posited that certain repair machines could eventually be miniaturized to such an extent that, as Feynman described, it might be feasible to "swallow the surgeon." This notion was integrated into Feynman's 1959 essay, "There's Plenty of Room at the Bottom."[2]

Given that nano-robots would be extremely small, it is likely that a substantial number of them would need to collaborate to accomplish both microscopic and macroscopic tasks. These swarms of nano-robots, which may either lack the ability to replicate (as seen in utility fog) or possess the capacity to replicate without constraints in natural environments (as illustrated by grey goo and synthetic biology), are frequently depicted in various science fiction narratives, including the Borg nano-probes in Star Trek and the episode "The New Breed" from The Outer Limits. Some advocates of nano-robotics, responding to the grey goo scenarios they previously helped to promote, argue that nano-robots capable of replicating outside a controlled factory setting are not essential for a viable nanotechnology. They contend that if self-replication were ever achieved, it could be designed to be inherently safe. Furthermore, they emphasize that their current strategies for developing and implementing molecular manufacturing do not involve unrestricted replicators.[3][4]

Robert Freitas has provided an extensive theoretical examination of nanorobotics, addressing specific design challenges such as sensing, power communication, navigation, manipulation, locomotion, and onboard computation within the framework of nanomedicine.[5]6] However, some of these discussions remain at a level of generality that does not translate into practical engineering solutions.

Nanorobots have effectively transformed energy supply into kinetic energy. Three distinct categories of powered nanorobots are outlined. Biohybrid systems integrate artificial nanostructures with motile microorganisms, serving as the driving force for the nanorobots.

Chemically powered nanorobots utilize uneven catalytic engines to selectively convert chemical fuels into movement. Physically powered nanorobots harness external energy sources, such as magnetic fields, ultrasound, or light, to generate translational motion, which is influenced by the design of the engine and the materials used. The atomic force microscope is a notable tool that can be considered in the design of nanorobotics. The field of nanorobotics holds significant promise for advancements in science and technology. Nanorobots have the potential to transport and deliver drugs directly to damaged cells. Furthermore, these nanorobots may facilitate tissue regeneration, cleanse blood vessels and airways, enhance physiological functions, and potentially mitigate the effects of aging. The capabilities of nanorobots range from disease elimination to the reversal of aging, offering personalized treatments with improved efficacy and reduced side effects that are currently unavailable.

Research in nanotechnology and nanoscience has significantly increased over recent years across various product categories. This field presents opportunities for the development of materials, particularly for medical applications, where traditional methods may fall short. The integration of nanotechnology in pharmaceuticals is expected to yield advanced and intelligent drug delivery systems, serving as a vital alternative to conventional dosage forms. Pharmaceutical nanotechnology is a highly specialized and innovative field poised to transform the pharmaceutical sector. It provides groundbreaking opportunities to address a range of diseases, facilitating the identification of antigens associated with conditions such as cancer, diabetes, and neurological disorders, as well as the detection of viruses and bacteria. Since the 1990s, nanotechnology has led to remarkable advancements in numerous healthcare applications. For instance, in diagnostics, nano-chips are employed for self-testing and home diagnostics for specific conditions. Other applications include the use of quantum dots for enhanced detection sensitivity and nano needles for performing surgeries on nanoscale structures within living cells and tissues without causing damage.

Nanorobots are envisioned as nanomachines capable of repairing damage that accumulates due to metabolic processes in living organisms. They will execute therapeutic procedures at the nanoscale on approximately 75 trillion cells that constitute the human body. The construction of these nanorobots involves several key components, including an onboard power supply, sensors, a nanocomputer, pumps, manipulators, and pressure tanks. Essential characteristics of nanorobots encompass swarm intelligence, self-assembly and replication, nano-information processing and programmability, as well as an interface architecture that bridges the nano and macro worlds. The integration of nanorobots in medicine presents a novel array of tools for disease treatment and enhancement of the human biological system. Medical nanorobotics holds the potential to provide innovative solutions for various human ailments and to improve overall biological functions. The design of medical nanorobots includes specialized types such as respirocytes, microbivores, clottocytes, pharmacytes (for targeted drug delivery), dentifrobots (dental nanorobots), and vasculoids, which serve as an artificial nanomechanical vascular system.

Literature Review

1. Tanisha Das et al (2024) studied the Drug delivery systems (DDSs), including micro and nanorobots with innovative propulsion mechanisms, enhance drug delivery precision in intricate physiological environments, reaching previously inaccessible areas. However, integrating them poses critical safety challenges like material selection, biocompatibility, mobility control, and long-term effects, hindering their practical application progress..[7]

2. Saksham Guha et al (2023) studied the Nanomachines (built on a molecular scale) can be used in medicine. Nanorobotics involves creating machines at the nanometer scale. Nanomedicine applies nanotechnology to medicine. Potential nanotech uses include tiny robots distributing drugs, conducting microsurgery, and using protein dynamics for power. Nanorobots' tools encompass medication storage, probes, blades, chisels for plaque removal, microwave emitters, ultrasonic signal generators for destroying cancer cells, electric electrodes, heating elements, and lasers. A cream with nanorobots could address skin issues. Other applications involve treating various ailments like gout, kidney stones, arthritis, parasites, cancer, and arteriosclerosis.[8]

3. Mr. Jaydeep Mehta et al (2023) studied the Robots which are used in various fields such as physics, chemistry, biology, medicine, engineering, and health sciences for creating and controlling nanorobots. These multidisciplinary areas necessitate careful planning by research and engineering departments. Healthcare is now focusing on improving scientific treatments with less invasive diagnostic methods, driven by advancements in nanotechnology. Nanorobots are utilized in treating cancer, removing blood clots, managing atherosclerosis, and eliminating parasites.[9]

4. Jatin V. Thake et al (2023) studied the Nanotechnology involves design, fabrication, and use of nanoscale structures and devices. It aims to enhance patient compliance and drug delivery in pharmaceuticals. Nanomedicine and nanorobots are key developments in this field. The technology enables disease diagnosis and treatment through nanostructures. It shows promise for cancer and AIDS treatment. This review covers recent advancements in nanotechnology for medication delivery, drug discovery, and cosmetics in pharmacy.[10]

5. Deepak Pokharkar et al (2021) studied the focus in healthcare is shifting towards improving medical treatments with minimally invasive strategies and nanotechnology, particularly nanorobotics. Nanorobots offer significant advantages over traditional methods in diagnosis and treatment, leveraging knowledge from molecular biology, chemistry, and physics at the nanometer scale. These tiny devices have diverse applications in medicine, such as early cancer detection and targeted drug delivery. This review outlines the design, mechanism, and medical uses of nanorobots.[11]

6. Indra Kumar Ghoshal et al (2020) studied the Nanorobotics involves creating tiny machines known as nanomachines at the molecular scale of a nanometre to treat medical conditions, a concept referred to as nanomedicine. This technology envisions microscopic robots delivering drugs or performing microsurgery within the body.[12]

7. Mengyi Hu et al (2020) studied the the field of micro/nanorobotics has garnered interest, especially in medical applications like targeted drug delivery and surgery. These tiny robots offer autonomous movement for delivering drugs precisely to inaccessible areas, powered by external (magnetic, light, etc.) or internal (chemical reactions) sources. This article also mentions cell-based and DNA origami micro/nanorobots. Despite promising prospects, in vivo research is currently limited, necessitating further biological experiments to confirm their drug delivery efficacy.[13]

8. Vijay Kishore et al (2014) studied the Nanorobotics, an emerging nanotechnology field, focuses on designing and constructing devices at atomic, molecular, or cellular levels. These tiny nanorobots are designed to travel within the human bloodstream, detecting target molecules to diagnose and treat diseases effectively. Innovations in nanorobotics have led to the creation of specific nanorobots like respirocytes, microbivores, and clottocytes, which mimic and substitute blood functions. These advancements offer promising solutions for medical treatments.[14]

9. Sachin S.Salunkhe et al (2013) studied the Nanotechnology, focusing on materials and devices at the nanometer scale, has gained attention in health care and drug delivery. Nanorobots, tiny robots optimized for specific functions and drug delivery, offer precise treatment targeting and reduced side-effects. The potential of nanorobots in medicine could revolutionize healthcare by enhancing diagnostics and therapeutics through nanorobotic technology, addressing damages and infections at a molecular level in the human body to mimic biological systems.[15]

10. Kal Renganathan Sharma et al (2012) studied the Submarine nanorobots are being developed for medical applications like branchy therapy and cancer treatment. Nanoparticles play a vital role in drug delivery systems, eye disorder treatment, and early diagnosis. Current nanomedicine research focuses on diagnostics, targeted cancer therapy, drug delivery, and tissue engineering. Novel therapeutic formulations using PLGA nanoparticles have been developed. Nanorobots have potential for targeted therapy and DNA repair. The possibilities of molecular assemblers are being debated. Fullerenes, like C60, are a unique form of carbon with diverse synthesis methods. Various nanostructuring techniques are discussed, including lithography, chemical vapor deposition, and thin film formation methods. Thermodynamically stable Carbon forms are diamond, graphite, C60, Buckminster Fullerene, and Carbon Nanotube. Molecular machines and supramolecular materials show promise in nanotechnology advancements. Gene expression studies, self-organizing nanorobots, biomimetic materials, and nanostructure characterization methods like SAXS and AFM are essential in this field.[16]

Aims - "Innovations in Nanotechnology and Exploring the EthicalImplications of Nanorobotics in Healthcare"

Objectives-

- Targeted drug delivery: Nanorobots can deliver drugs to hard-to-reach areas of the body, such as tumors, by moving autonomously.

- Cancer treatment: Nanorobots can detect and treat cancer by delivering cancer-fighting chemicals directly to tumors.
- Aneurysm rupture: Nanorobots can reduce bleeding and act as a localization tool to help with aneurysm rupture treatment.
- Genetic diseases: Nanorobots can replace damaged chromosomes with artificial ones to treat genetic diseases.
- Microsurgery: Nanorobots can be used in minimally invasive microsurgery to reduce trauma and improve recovery times.
- Tissue engineering: Nanorobots can be used in tissue engineering.
- Blood clot removal: Nanorobots can be used to split up blood clots.

- Improve diagnosis and treatment
- Nanomedicine can help improve the diagnosis, treatment, and follow-up of many diseases. For example, nanowire detectors can detect cancer proteins in a small amount of blood in about five minutes.
- Nanomedicine can be tailored to each individual's tumor for better performance.
- Improve drug delivery
- Nanoparticles can transport drugs to targeted sites without toxic effects. For example, albumin-based nanoparticles can make drugs more stable and circulate longer in the blood.
- Improve imaging techniques
- Albumin-coated contrast agents can be used in imaging techniques to better visualize specific tissues.
- Create self-powered medical devices
- Nanogenerators can convert mechanical energy from body movement into electricity to power implantable medical devices.[17]

Components of Nanorobots

Nanorobots consist of several essential components, including a power supply, fuel buffer tank, sensors, motors, manipulators, onboard computers, pumps, pressure tanks, and structural support. The substructures of a nanorobot encompass the following elements:

1. Payload - This hollow section is designed to contain a small quantity of drug or medicine. Nanorobots can navigate through the bloodstream and release the medication at the targeted site of infection or injury.

2. Micro camera - A miniature camera may be integrated into the nanorobot, allowing the operator to manually guide the device as it moves through the body. [18]

3. Electrodes - Electrodes affixed to the nanorobot can function as a battery by utilizing the electrolytes present in the blood. These electrodes can also eliminate cancer cells by generating an electric current that heats the cells to the point of destruction.

4. Lasers - The nanorobot may be equipped with lasers capable of incinerating harmful substances such as arterial plaque, blood clots, or cancer cells.

5. Ultrasonic signal generators - These generators are employed when nanorobots are tasked with targeting and eliminating kidney stones.

6. Swimming tail - To facilitate movement within the body, the nanorobot requires a propulsion mechanism that enables it to travel against the blood flow. [19]

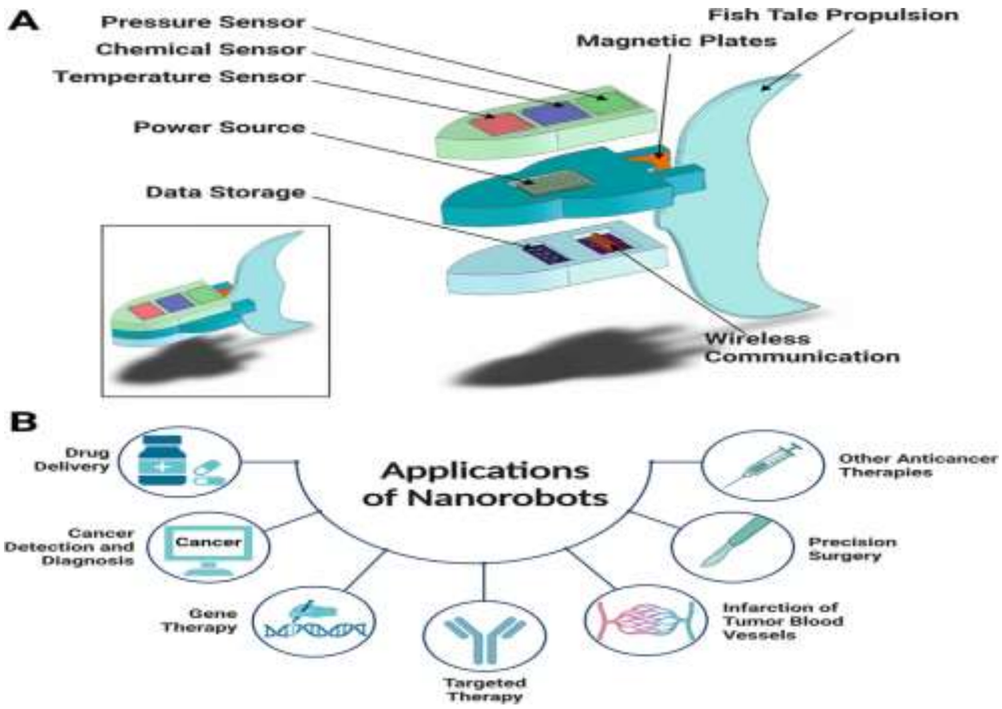

Fig 1 [24] – Components of nanorobots

Types of Nanorobots

The types of nanorobots designed by Robert A. Freitas Jr as artificial blood are: i. Respirocytes. ii. Microbivores. iii. Clottocytes.

Respirocytes are theoretical, microscopic, synthetic red blood cells designed to replicate the functions of natural red blood cells, thereby augmenting or potentially replacing the capabilities of the human respiratory system. The concept of respirocytes was introduced by Robert A. Freitas Jr. in his 1998 publication titled "A Mechanical Artificial Red Blood Cell: Exploratory Design in Medical Nanotechnology."[22]

These respirocytes represent a form of molecular nanotechnology, a domain that remains in its nascent and entirely speculative stage of advancement. Present technological capabilities are inadequate for the construction of respirocytes, primarily due to challenges related to energy requirements, atomic-scale manipulation, immune responses, toxicity, as well as computation and communication.[20]

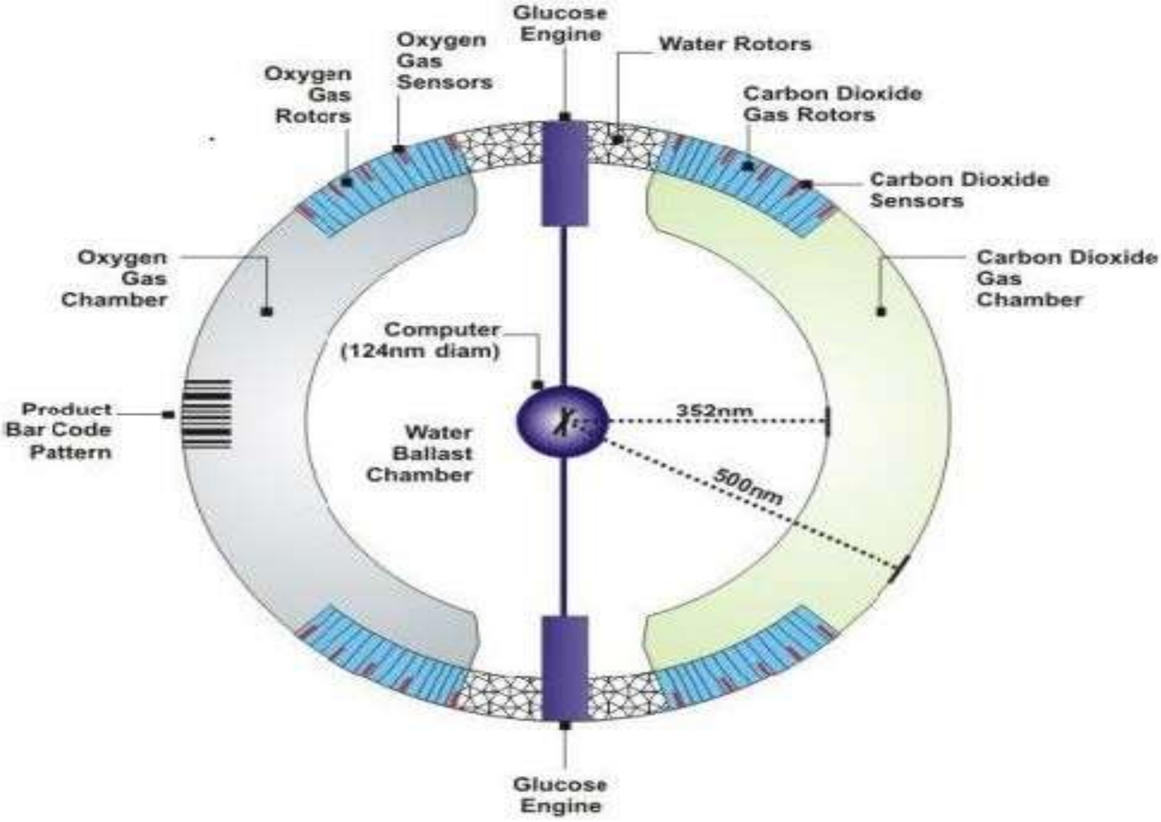

Fig 2- Respirocytes [25]

Microbivores

Microbivores are advanced nanorobots designed to function as artificial white blood cells, also referred to as nanorobotic phagocytes. These spheroid devices, constructed from diamond and sapphire, have a major axis diameter of 3.4 µm and a minor axis diameter of 2.0 µm, comprising 610 billion meticulously arranged structural atoms. Their primary role is to capture pathogens present in the bloodstream and decompose them into smaller molecular fragments. The microbivore operates through the process of phagocytosis, effectively absorbing and digesting these pathogens.

The microbivore is composed of four essential components:

i. An array of reversible binding sites.

ii. An array of telescoping grapples.

iii. A morcellation chamber.

iv. A digestion chamber.

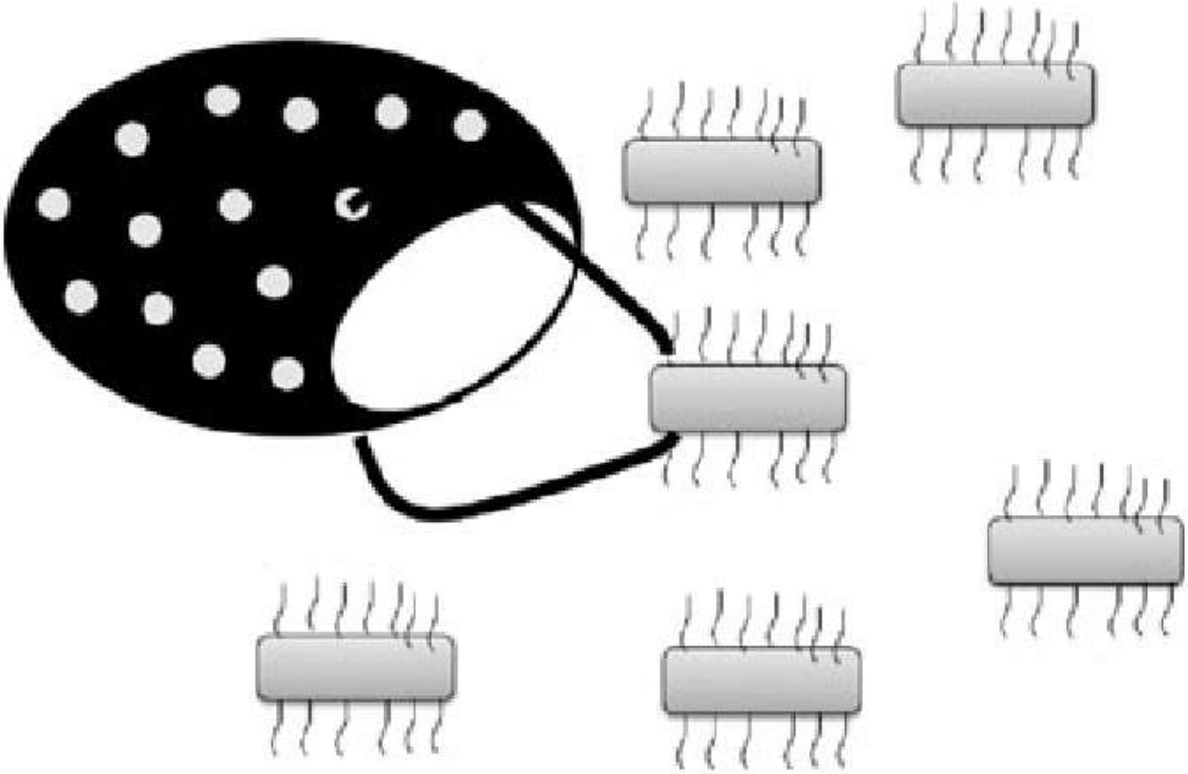

Fig 3- Microbivore [26]

During its operational cycle, a target bacterium adheres to the surface of the microbivore via a species-specific reversible binding site. A collision between the bacterium and the microbivore facilitates close contact, enabling the binding site to recognize and form a weak attachment to the bacterium. A total of 9 distinct antigenic markers are employed to confirm the binding event, ensuring the identification of the target microbe. These markers are distributed across 275 disk-shaped regions on the microbivore, with 20,000 copies of each marker set present. Once the bacterium is securely bound, the telescopic robotic grapples extend from the surface and attach to the bacterium, providing a stable grip. The grapples then transport the bacterium from the binding site to the ingestion port. Subsequently, the bacterium is drawn into the morcellation chamber, where it is minced into nanoscale fragments. The resulting remnants are then pushed into the digestion chamber, which contains a pre-programmed array of digestive enzymes.[21]

Clottocytes

Hemostasis refers to the blood clotting process that occurs following damage to the endothelial cells of blood vessels, facilitated by platelets. These platelets can be activated when they come into contact with exposed collagen from injured blood vessels. The entire natural blood clotting process typically takes between 2 to 5 minutes. Advances in nanotechnology have demonstrated the potential to decrease both clotting time and blood loss. In some patients, blood clots may form irregularly, a condition that is often managed with corticosteroid medications. [21]However, corticosteroid treatment can lead to various side effects, including hormonal imbalances, potential lung damage, and allergic reactions. The concept of the clottocyte introduces an artificially designed mechanical platelet that aims to achieve hemostasis in approximately 1 second. This spherical nanorobot, measuring around 2 μm in diameter, is powered by serum-oxyglucose and contains a compactly folded fiber mesh. The response time of the clottocyte is estimated to be 100 to 1000 times faster than that of the natural hemostatic system. The fiber mesh is designed to be biodegradable, and upon its release, a soluble film coating will dissolve upon contact with plasma, revealing a sticky mesh that facilitates clotting.[23]

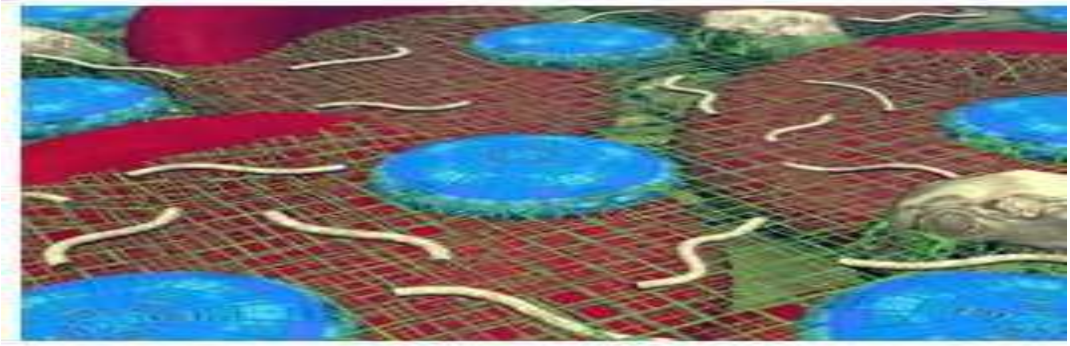

Fig 4- Clottocytes [27]

APPLICATIONS

1. Application in diabetes

Nanorobots are emerging as a promising innovation in the healthcare sector, enhancing medical instrumentation, diagnostics, and therapeutic interventions. For individuals with diabetes, the necessity of taking small blood samples multiple times daily to monitor glucose levels can be both uncomfortable and inconvenient. To mitigate this issue, continuous glucose monitoring through medical nanorobotics can be employed. This automated data collection enables healthcare providers, including doctors and specialists, to deliver real-time medical care, thereby optimizing the patient's treatment plan.[28]

The deployment of numerous independent nanorobots presents various advantages. The manufacturing of medical nanorobots should incorporate embedded and integrated devices. Maintaining appropriate glucose levels in the bloodstream is crucial for ensuring healthy human metabolism, and achieving the correct balance is vital for the diagnosis and management of diabetes. For adults with diabetes, glycemic levels must remain within a predetermined target range. Typically, individuals with diabetes aim to maintain their blood glucose levels (BGLs) between 90 and 130 mg/dL (5.0–7.2 mmol/L) before meals, and below 180 mg/dL (10.0 mmol/L) thereafter.[29]

2. Nanorobots in Cancer Therapy[30] [31]

In the real of cancer therapy, the primary challenges lie in targeting and localized drug delivery. To address the limitations of traditional treatment methods, it is essential to specifically target cancer cells while minimizing the impact on healthy tissues to reduce the risk of drug toxicity. Theoretically, the envisioned nanorobot should perform the following functions:

1. Utilize nano-sensors to detect the presence of malignant cells within the body.

2. Employ nano-carriers to transport the combined nano-sensor and nano-drug encapsulate to the vicinity of cancerous tissues.

3. Utilize nano drug delivery particles to encapsulate therapeutic agents for targeted delivery at specific cancerous sites, ensuring controlled release of the drugs.

4. Incorporate a nano-computer or brain to coordinate these activities within the complex in-vivo environment.

3. Nanorobots in Dentistry

Nanorobots utilized in dental care are incorporated into products such as mouthwash and toothpaste, enabling them to access all subgingival surfaces. This technology effectively metabolizes trapped natural substances into harmless and odorless vapors. When properly designed, these dental nanorobots can identify and eliminate pathogenic microorganisms present in plaque and other areas. These minuscule devices are essentially mechanical entities that deactivate themselves safely upon ingestion. To enhance oral hygiene, mouthwash infused with intelligent nanorobots can target and eradicate harmful bacteria while allowing beneficial oral flora to thrive in a healthy environment. Additionally, these devices can detect and remove food particles, plaque, or tartar, facilitating their rinsing away. They help prevent tooth decay and provide a continuous defense against halitosis.

In the context of cavity treatment and restoration, multiple nanorobots can work simultaneously on the enamel of teeth, operating invisibly to the naked eye. Furthermore, nanorobots can be employed to administer anesthesia; a colloidal suspension containing millions of active analgesic micron-sized dental nanorobots can be applied to the patient's gums. Upon contact with the crown or mucosal surface, these mobile nanorobots navigate painlessly into the dentin by migrating through the gingival sulcus and into the lamina propria. Once they reach the dentin, they enter the dentinal tubules and proceed toward the pulp under nanocomputer guidance. This migration from the enamel surface to the pulp occurs within approximately 100 seconds. Once positioned within the pulp, the analgesic nanorobots, controlled by the dentist, can effectively inhibit all sensitivity in the specific tooth requiring treatment.[32]

4. Hematology

The applications of nanorobotics in hematology are extensive, ranging from emergency transfusions of non-blood oxygen-carrying compounds to the restoration of primary hemostasis. A notable device currently under development is a nanorobot known as a respirocyte. This robotic entity is engineered to perform three primary functions as it navigates through the bloodstream. Firstly, it collects oxygen while traversing the respiratory system for subsequent distribution throughout the circulatory system. Secondly, it gathers carbon dioxide from tissues for expulsion into the lungs. Lastly, it metabolizes circulating glucose to power its own operations. The respirocyte is designed to carry 236 times more oxygen per unit volume compared to red blood cells. The advancement and implementation of this technology could provide an effective and lower-risk alternative to blood transfusions.

Hemostasis is a complex process involving multiple steps, with various promoters and inhibitors that regulate thrombosis and fibrinolysis. When hemostasis functions correctly, it is highly effective in stopping bleeding and facilitating vessel repair. However, impairments in physiological hemostatic mechanisms, such as thrombocytopenia, can occur. Patients receiving platelet transfusions face risks of pathogen contamination and potential immune responses. The proposed nanorobot for this purpose is referred to as an artificial mechanical platelet, or "clottocyte." Additionally, another potential application of nanorobots in this field is as phagocytic agents, termed "Microbivores." These robots can be designed with a wide array of customizable binding sites on their exterior surface, allowing them to target various antigens or pathogens, ranging from HIV to E. coli.

5. Gene Therapy

By analyzing the molecular structures of DNA and proteins present within the cell, advanced medical nanorobots can effectively address genetic disorders. Within the nucleus of human cells, an assembly of repair vessels performs various genetic maintenance functions. The nanodevice extends its specialized robotic arms to gently extract an unwound strand of DNA through an outlet for examination. Simultaneously, the upper arms detach regulatory proteins from the DNA strand and position them within a designated intake port.

The molecular configurations of both DNA and proteins are compared against data stored in a larger nanocomputer located outside the nucleus, which is connected to the cellular repair vessel via a communication link. Any identified irregularities in the structures are rectified, and the proteins are reattached to the DNA strand, allowing it to coil back into its original form, measuring just 50 nanometers in diameter. Although this repair vessel is smaller than most viruses and bacteria, it is highly effective in delivering therapies and cures.[33]

6. Nanorobots in Surgical Applications

Surgical nanorobots can be introduced into the human body via the vascular system or through the ends of catheters, allowing access to various vessels and internal cavities. These nanorobots, which can be programmed or directed by a surgeon, function as semi-autonomous surgical assistants within the body. They are capable of performing a range of tasks, including diagnosing pathologies and correcting lesions through nanoscale manipulation, all while being coordinated by an onboard computer that maintains communication with the supervising surgeon through coded ultrasound signals.

Neurosurgery stands to gain significantly from the advancements in engineering technology. The benefits include enhanced detection of pathologies, minimally invasive intracranial monitoring, and targeted drug delivery, among others. One of the most effective strategies to reduce morbidity and mortality in surgical practice is the preemptive treatment of cerebral aneurysms before they rupture, as the rupture of such aneurysms is associated with a high fatality rate. Nanorobotics offers a promising alternative for the early detection of new cardiovascular diseases or for closer monitoring of existing conditions. Cacalcanti et al. have proposed a design for an intravascular nanorobot capable of identifying aneurysm formation by detecting elevated levels of nitric oxide synthase protein within the affected blood vessel.[34]

Expected Outcome

Nanorobots are expected to have many positive outcomes in pharmacy, including:

- Targeted drug delivery: Nanorobots can deliver drugs and molecules to specific locations in the body, such as tumors, without harming normal cells.
- Early diagnosis: Nanorobots can help diagnose health conditions.
- Improved vaccines: Nanobots can be used to improve vaccines.
- Reduced adverse effects: Nanorobots can reduce the adverse effects of existing therapies, such as chemotherapy damage.
- More precise surgery: Nanorobots can perform surgical procedures more precisely.
- Augmented human biological systems: Nanorobots could be used to augment human biological systems, such as developing artificial mitochondria.

- Improved treatment of infections: Nanorobots could be used to treat infections, such as septicemia, by clearing pathogens from the body.

Nanorobots are made of nanomaterials and are constructed using sophisticated submicron devices. However, there are some challenges to using nanorobots, such as:

- Controlling their direction can be difficult.
- They can be sensitive to ionic environments.
- They may exhaust energy as reactions proceed.
- Safety concerns surround the "fuel" and reaction products.[35]

REFERENCES

1. Vaughn JR. "Over the Horizon: Potential Impact of Emerging Trends in Information and Communication Technology on Disability Policy and Practice". National Council on Disability, Washington DC, 2006; 1–55.

2. Feynman, Richard P. (December 1959). "There's Plenty of Room at the Bottom". Archived from the original on 2010-02-11. Retrieved 2016-04-14.

3. Zyvex: "Self replication and nanotechnology" "artificial self replicating systems will only function in carefully controlled artificial environments ... While self replicating systems are the key to low cost, there is no need (and little desire) to have such systems function in the outside world. Instead, in an artificial and controlled environment, they can manufacture simpler and more rugged systems that can then be transferred to their final destination. ... The resulting medical device will be simpler, smaller, more efficient and more precisely designed for the task at hand than a device designed to perform the same function and self replicate. ... A single device able to do [both] would be harder to design and less efficient."

4. "Foresight Guidelines for Responsible Nanotechnology Development" Archived 2019-06-06 at the Wayback Machine "Autonomous self-replicating assemblers are not necessary to achieve significant manufacturing capabilities." "The simplest, most efficient, and safest approach to productive nanosystems is to make specialized nanoscale tools and put them together in factories big enough to make what is needed. ... The machines in this would work like the conveyor belts and assembly robots in a factory, doing similar jobs. If you pulled one of these machines out of the system, it would pose no risk, and be as inert as a light bulb pulled from its socket."

5. R.A. Freitas Jr., Nanomedicine, Vol. I: Basic Capabilities, Landes Bioscience, Georgetown TX, 1999; http://www.nanomedicine.com/NMI.htm Archived 2015-08-14 at the Wayback Machine.

6. R.A. Freitas Jr., Nanomedicine, Vol. IIA: Biocompatibility, Landes Bioscience, Georgetown TX, 2003; http://www.nanomedicine.com/NMIIA.htm.

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16. Kal Renganathan Sharma Department of Chemical Engineering Roy G. Perry College of Engineering Prairie View A & M University Prairie View, TX 77446

17. AI Overview

18. Kharwade, M., M., Nijhawan, and S., Modani, "Nanorobots: A Future Medical Device in Diagnosis and Treatment", Research Journal of Pharmaceutical, Biological and Chemical Sciences, 4 (2): 1299-1307, 2013.

19. Mishra, J., A. K., Dash, and R., Kumar, "Nanotechnology Challenges: Nanomedicine: Nanorobots", Journal of Pharmaceuticals, 2 (4): 112-119, 2012

20. Robert A. Freitas Jr. (1998). "Exploratory Design in Medical Nanotechnology: A Mechanical Artificial Red Cell". Artificial Cells, Blood Substitutes, and Immobil. Biotech. (26): 411–430.

21. Wilner, M.E., Bio-Inspired and Nanoscale Integrated Computing. John Wiley & Sons, Inc., 2009.

22. Robert, A. F. J., "Microbivores: Artificial Mechanical Phagocytes using Digest and Discharge Protocol", Journal of Evolution and Technology, 14: 1-52, 2005.

23. Boonrong, P., and B., Kaewkamnerdpong, "Canonical PSO based Nanorobot Control for Blood Vessel Repair", World Academy of Science, Engineering and Technology, 5: 428-433, 2011

24. https://images.app.goo.gl/sJA6PnWjN9yPqJQG6

25. https://images.app.goo.gl/mruXFG14j5Xhe5n3A

26. https://images.app.goo.gl/SifKqMzu3pbTp1J16

27. https://images.app.goo.gl/Fg1CYQcRs8ApoMdE8

28. Debjit B, Chiranjib, Margret chandira R, Jayakaret B. Role of nanotechnology in novel drug delivery system. J Pharm Sci and Tech, 2009; 1(1): 20-35.

29. Adriano C, Bijan S, Luiz C, Kretly. Medical nanorobotics for diabetes control. Nanomedicine: Nanotechnology, Biology, and Medicine, 2008;4:127–38

30. Gates BD, Xu Q, Stewart M, Ryan D, Willson GG, Whitesides GM. New approaches to nanofabrication: molding, printing, and other techniques. Chem Rev, 2005; 105:1171-96.

31. Deepak N Kapoor, AmitBansal, Ruchi Sharma, SanjuDhawan.Advanced nanomedicine: Present contributions and future expectations.American Journal of Phytomedicine and Clinical Therapeutics, 2013; 1(2):124-39.

32. Padovani GC, Feitosa VP, Sauro S, Tay FR, Duran G, Paula AJ and Duran N, Advances in dental materials through nanotechnology facts, perspectives and toxicological aspects, Trends in Biotechnology, 2015; 33: 621-36.

33. Abhilash M:NANOROBOTS: International Journal of Pharma and Bio Sciences, 2010; 1(1): 1-10.

34. . Cavalcanti, L. Rosen, L. C. Kretly, Moshe. Rosenfeld, ShmuelEinav, Nanorobotics Challenges in Biomedical Applications, Design and Control, IEEE ICECS Int"l Conf. on Electronics, Circuits and Systems,Tel-Aviv, Israel, December 2004.

35. Ai Overview