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NANOROBOTS: MINIATURE MARVELS IN THE WORLD OF BIOMEDICATION

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ABSTRACT

In the Revolutionary world of Medications the versatile drug delivery is enhancing day by day through using nanorobots. Nanorobots can deliver the drug through microscopic devices operating at the nanoscale. This review mostly deals with the nanorobots importance in the Biomedication their role in the diagnostics, components, types, and mechanisms of action. These tiny machines can be engineered with diverse functionalities, including targeted drug delivery. By leveraging their size and unique properties, nanorobots can navigate complex biological environments, delivering therapeutic agents directly to diseased cells while minimizing damage to healthy tissues. Their biodegradability ensures safe elimination from the body after completing their mission. Advanced control and communication methods enable precise manipulation and tracking of these devices. The limitations for this advanced tiny machines are also discussed in this article. This review delves the overview of a nanorobots of the targeted drug delivery mechanism in the revolutionary world of Biomedication. Future developments in nanorobots could lead to the creation of more complex medications with multiple diagnostics for biodegradability and responsive delivery.

KEYWORDS: Nanorobots, Nanotechnology, Nanodiagnostics, Gene therapy, Biodegradability.

INTRODUCTION

The field of nanotechnology has emerged as a revolutionary approach in various scientific disciplines, particularly in pharmaceuticals. Among its numerous applications, nanorobots have garnered significant attention for their potential in enhancing diagnostic capabilities, often referred to as nano diagnostics.[1] These microscopic devices, operating at the nanoscale (1-100 nanometers), integrate engineering, biology, and materials science to perform tasks that traditional diagnostic methods cannot achieve. The ability of nanorobots to interact with biological systems at the cellular and molecular levels positions them as pivotal tools in the future of pharmaceutical diagnostics.[2]

The role of nanorobots in nanodiagnostics

Nanorobots are designed to perform specific functions, such as detecting diseases, monitoring biological processes, and delivering therapeutic agents. Their small size allows them to navigate through biological environments with ease, reaching areas that are otherwise inaccessible to larger diagnostic tools. For instance, they can transverse blood vessels and target specific cells or tissues, enabling precise diagnostics and real-time monitoring of disease progression.

One of the most promising applications of nanorobots in nanodiagnostics is their use in cancer detection and monitoring. Traditional imaging techniques often fall short in detecting tumors at early stages. However, nanorobots can be engineered to bind specifically to cancer biomarkers—molecules that indicate the presence of cancer cells. By delivering imaging agents or fluorescent markers directly to these targeted sites, nanorobots enhance the sensitivity and specificity of cancer diagnostics, allowing for earlier intervention and improved patient outcomes.[3]

Nanorobots can utilize various mechanisms to carry out their diagnostic functions. For example, they can be equipped with biosensors that detect specific biomolecules associated with diseases. These biosensors can generate signals that indicate the presence or concentration of these biomarkers, providing valuable information for diagnosis. Additionally, nanorobots can be programmed to respond to specific stimuli, such as changes in pH or temperature-enabling them to release diagnostic agents only when they reach the intended target.

Moreover, advancements in materials science have led to the development of multifunctional nanorobots capable of performing multiple diagnostic tasks simultaneously. These devices can integrate imaging, sensing, and therapeutic capabilities, making them versatile tools in personalized medicine. For example, a single nanorobot could identify cancer cells, release a drug to target those cells, and provide imaging data to monitor treatment efficacy.[4]

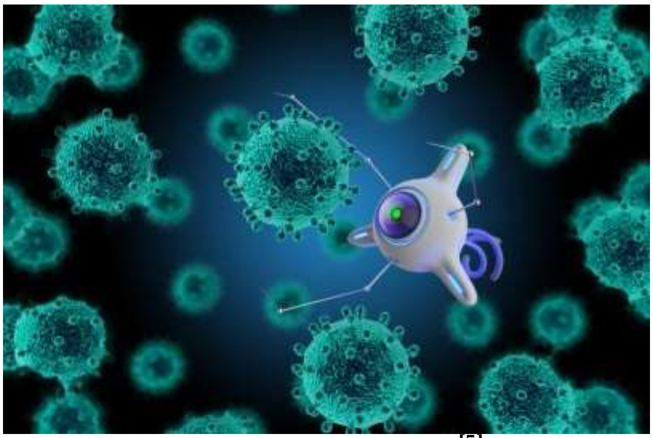

Figure 1: Nanorobot.[5]

Components

1. Payload

Function: This is the core of the nanorobot's mission. It carries the therapeutic or diagnostic element.

Drugs: Nanorobots could deliver specific drugs to targeted cells or tissues, enhancing therapeutic effects and minimizing side effects.

Gene therapy: Nanorobots might carry genetic material for gene therapy, replacing faulty genes or introducing new ones.

Diagnostic agents: Nanorobots could carry agents that detect specific biomarkers, helping in early diagnosis of diseases.[6][7]

2. Micro-Camera

Function: A miniature camera integrated into the nanorobot could capture images of the cellular and molecular level within the body.

Diagnostic imaging: This camera could be used for real-time monitoring of biological processes, tissue damage, or disease progression.

Surgical guidance: Nanorobots could use a micro-camera to guide surgical interventions, providing precise visualization of the surgical site.[6][8][9]

3. Lasers

Function: Lasers could be used for a variety of purposes such as

Photodynamic Therapy (PDT): Nanorobots equipped with lasers could activate light-sensitive drugs, targeting and destroying specific cells, such as cancer cells.

Tissue Ablation: Lasers could be used to precisely remove targeted tissues, such as tumors or blood clots.[6][10][11]

4. Electrodes

Function: Electrodes allow nanorobots to interact with electrical signals in the body.

Neuromodulation: Nanorobots could use electrodes to stimulate or inhibit specific neurons, potentially treating neurological disorders.

Electrical Stimulation: Nanorobots could deliver electrical signals to targeted tissues, promoting healing or modulating cellular activity.[6][12]

5. Ultrasonic signal generators

Function: Nanorobots could use ultrasonic waves to communicate with external devices or manipulate their environment.

Communication: Nanorobots could send and receive ultrasonic signals, transmitting data about their location, health status, or detected biomarkers.

Sonic manipulation: Nanorobots could use ultrasonic waves to manipulate cells or tissues, perhaps even clearing blockages in blood vessels.[6][13]

6. Swimming tail

Function: A swimming tail would provide propulsion for nanorobots, enabling them to navigate through body fluids. Flagella-like: This tail could be inspired by the flagella found in bacteria, allowing for efficient swimming motions.

Magnetic propulsion: A magnetic swimming tail could be manipulated by external magnetic fields, providing precise control over the nanorobot's movement.[6][14][15]

7. Actuators

These are tools that allow the nanorobot to engage in physical interactions with the body, such circulating blood, dispensing medication, or conducting surgery.[16]

8. Sensors

One of the most crucial components of nanobots is their sensors. Applications for nanobots have tested mechanical, thermal, optical, magnetic, chemical, and biological sensors.[17]

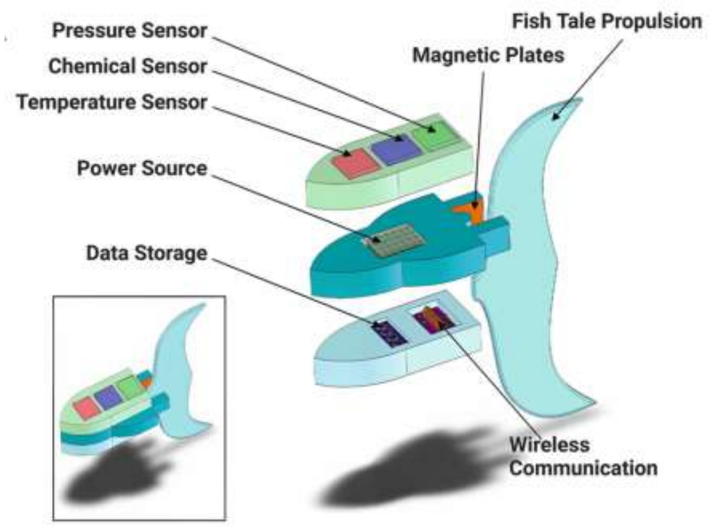

Figure 2: Components of nanorobots.[18]

Important considerations

Miniaturization: The challenge lies in building these components at the nanoscale while maintaining their functionality.

Biocompatibility: Materials used for these substructures must be biocompatible, preventing adverse reactions within the body.

Power and Control: Providing sufficient power and developing sophisticated control systems for these intricate devices are ongoing challenges.[7][8][12]

Types

I. Pharmacyte
II. Respirocyte
III. Microbivores
IV. Chromallocyte
V. Clottocytes
VI. DNA nanobots
VII. Helices
VIII. Nanorods

I. Pharmacyte

This medical nanorobot is between 1-2 µm in size. In the tanks, these nanobots utilized to transport a specific medication. Mechanical sorting pump systems are used to control it. Pharmacyte has chemotactic sensors or molecular markers for complete targeting precision. The onboard power source consists of glucose and oxygen that are taken from the surrounding environment, including the cytosol, intestinal fluid, and blood.[5]

Mechanism of Action

1. Targeting

Passive targeting: Pharmacytes could be designed to accumulate in specific tissues due to their physical properties. For example, lipid-coated nanorobots might preferentially accumulate in tumors due to the enhanced permeability and retention (EPR) effect.

Active targeting: Pharmacytes could be equipped with ligands (specific molecules) that bind to receptors found on target cells, ensuring delivery directly to the desired location. This could involve targeting tumor-specific antigens for cancer therapy or receptors on inflammatory cells for autoimmune disease treatment.

2. Drug delivery

Encapsulation: Pharmacytes could encapsulate drugs within their structure, potentially using nano-carriers like liposomes or micelles. This would protect the drug from degradation in the bloodstream and ensure controlled release.

Controlled release: Pharmacytes could be programmed to release the drug based on specific triggers like pH changes, enzyme activity, or external stimuli. This could provide sustained drug release, reducing the need for frequent administration.

3. Sensing and Feedback

Biomarker detection: Pharmacytes could be equipped with sensors to detect specific biomarkers associated with disease progression or treatment efficacy.

Feedback mechanism: The detected information could trigger a response from the Pharmacyte, such as adjusting drug release rates or communicating with external devices for monitoring and adjustments.

4. Internal manipulation

Cellular repair: Pharmacytes could be equipped with tools to repair damaged cells. This could involve delivering growth factors to stimulate regeneration or carrying enzymes to break down toxic substances within cells.

Microsurgical tasks: Pharmacytes could be designed to perform microsurgical procedures like removing small tumors or clearing blockages in blood vessels.

5. Power and Propulsion

Fuel cells: Pharmacytes could be powered by biocompatible fuel cells that utilize glucose or other readily available energy sources within the body.

Ultrasonic propulsion: Nanorobots could use ultrasonic waves for locomotion, allowing them to navigate through body fluids.

6. Biodegradability

Biodegradable Materials: Pharmacytes could be constructed using materials that degrade safely within the body after completing their tasks, preventing long-term accumulation and potential toxicity.[19][20]

II. Respirocyte

It is Artificial Oxygen Carrier nanobot. The source of its power is endogenous serum glucose compared to red blood cells (RBCs), this artificial cell can supply tissues with 236 times more oxygen per unit volume.[5]

Mechanism of action

Resiprocyte is a sophisticated nanorobot designed for advanced drug delivery and therapeutic applications. Its mechanism of action is centered around its ability to navigate biological environments with precision, delivering therapeutic agents to specific target sites while minimizing side effects. Below are the key components and mechanisms that define how Resiprocyte operates:

1. Design and Composition

Resiprocyte is typically constructed from biocompatible materials such as lipids, polymers, or inorganic nanoparticles. The design often includes a core-shell structure, where the core encapsulates therapeutic agents (e.g., drugs, genes, or proteins) and the shell provides stability and facilitates interaction with biological systems.

2. Targeting mechanism

Resiprocyte employs various targeting strategies to ensure that it reaches the desired site of action:

Ligand-Receptor interaction: The surface of Resiprocyte can be functionalized with ligands that specifically bind to receptors overexpressed on target cells (e.g., cancer cells). This selective binding enhances the uptake of the nanorobot by the target cells.

Passive targeting: Due to their nanoscale size, Resiprocyte particles can exploit the enhanced permeability and retention (EPR) effect, which allows them to accumulate in tumor tissues more effectively than in normal tissues.

3. Stimuli-Responsive release

One of the hallmark features of Resiprocyte is its ability to release its therapeutic payload in response to specific stimuli:

pH-Responsive release: The shell may be engineered to degrade or change permeability in acidic environments, such as those found in tumor microenvironments, allowing for localized release of the drug.

Temperature or Enzyme-Responsive mechanisms: Resiprocyte can also be designed to respond to changes in temperature or the presence of specific enzymes, triggering the release of its contents at the target site.

4. Drug delivery process

The drug delivery process involves several steps:

Circulation: After administration (e.g., intravenous injection), Resiprocyte circulates in the bloodstream, where it can evade immune detection and avoid clearance by the reticulo endothelial system.

Targeting and Binding: Upon reaching the target area, Resiprocyte binds to target cells through specific interactions facilitated by surface ligands.

Internalization: Following binding, Resiprocyte is internalized by the target cells via endocytosis, a process where the cell membrane engulfs the nanorobot and forms an internal vesicle.

Payload release: Once inside the cell or in the vicinity of the target tissue, the therapeutic agents are released in a controlled manner due to the aforementioned stimuli-responsive mechanisms.

5. Biosensing capabilities

In addition to drug delivery, Resiprocyte can be equipped with biosensors that detect specific biomarkers within the biological environment. This enables:

Real-Time monitoring: The ability to monitor therapeutic responses or disease progression by detecting changes in biomarker levels.

Feedback mechanisms: Providing data that can inform further treatment decisions or adjustments in therapy based on real-time analysis.[21][22][23]

III. Microbivores

It is a spheroidal oblate device used in nanomedicine. The nanobot can continuously use up to 200 pW of power, which it uses to break down imprisoned microorganisms. Additionally, in terms of volume/sec digested per unit volume of phagocytic agent, it can phagocyte about 80 times more efficiently than macrophage agents.[5]

Mechanism of Action

1. Target recognition

Microbial antigens: Microbivores could be engineered to recognize specific antigens on the surface of pathogenic bacteria, viruses, or fungi. These antigens could be unique to the target microbe, ensuring precise targeting and minimizing harm to beneficial bacteria.

Cellular signals: Microbivores could be programmed to detect specific signals released by infected cells or tissues, allowing them to home in on areas of infection.

2. Microbial elimination

Phagocytosis: Microbivores could encapsulate and engulf target microbes, similar to the process of phagocytosis by immune cells, effectively "eating" them.

Antimicrobial agents: Microbivores could deliver potent antimicrobial agents directly to the target microbes, inhibiting their growth or killing them. These agents could be antibiotics, antiviral drugs, or antifungal agents.

Disruption of microbial structures: Microbivores could be equipped with tools to physically disrupt microbial structures, like cell walls or viral envelopes, leading to their destruction.

Immune system modulation: Microbivores could modulate the immune response, enhancing the body's natural defenses against the infection. For example, they could release signals to activate immune cells like macrophages or neutrophils, increasing their antimicrobial activity.

3. Monitoring and Communication

Microbial detection: Microbivores could carry sensors to detect and report on the presence and quantity of target microbes, providing real-time information about the infection.

Communication with immune cells: Microbivores could communicate with immune cells, sharing information about the infection and coordinating the immune response.

External feedback: Microbivores could communicate with external devices, such as medical sensors, to provide data about the infection and treatment progress.

4. Biodegradability

Safe degradation: After completing their tasks, Microbivores could be designed to break down into harmless components within the body, preventing long-term accumulation and potential toxicity.[23]

IV. Clottocytes

This nanobot can stop bleeding right away. These roughly spheroidal blood cells without a nucleus are also known as artificial mechanical platelets. At the site of bleeding, platelets clump together and become active. Then they assist in stopping the bleeding by stomping the blood artery. Additionally, they transport chemicals that aid in coagulation.[5]

Mechanism of action

1. Targeted delivery

Magnetic guidance: Clottocytes could be made of magnetic materials and guided to the clot location using external magnetic fields. This allows for precise targeting, avoiding unnecessary exposure to healthy tissues.

Blood vessel recognition: Clottocytes could be equipped with sensors that detect specific markers associated with blood clots, like fibrin or thrombin, enabling them to identify and target clots directly.

2. Clot dissolution

Enzyme delivery: Clottocytes could carry enzymes like plasminogen activators (e.g., tissue plasminogen activator - tPA) or fibrinolytic enzymes that directly break down the fibrin meshwork of the clot.

Mechanical disruption: Clottocytes could use tiny mechanical tools or ultrasound waves to physically disrupt the clot structure, aiding in its breakdown.

Anti-Platelet agents: Clottocytes could deliver anti-platelet drugs to the clot, preventing further platelet aggregation and clot growth.

3. Clot stabilization

Anti-Inflammatory agents: Clottocytes could deliver anti-inflammatory drugs to the clot site, reducing inflammation and minimizing tissue damage associated with clot formation.

Anti-Coagulation agents: Clottocytes could release anti-coagulation agents, inhibiting further clot formation and reducing the risk of recurrence.

4. Communication and Monitoring

Ultrasonic signals: Clottocytes could communicate with external devices using ultrasonic signals, providing real-time information about their location, clot dissolution progress, and surrounding tissue conditions.

Biomarkers: Clottocytes could carry sensors to detect and report on biomarkers associated with clot formation or dissolution, enabling physicians to monitor treatment effectiveness.

5. Biodegradability

Safe degradation: After completing their task, Clottocytes could be designed to degrade safely within the body, preventing long-term accumulation and potential adverse effects.[22]

V. Chromallocyte

They fight aging by replacing complete chromosomes in individual cells, erasing the consequences of cumulative gene damage and hereditary diseases. The repair machine typically operates inside a cell, first assessing the situation by looking at the contents and activity of the cell before acting by moving along molecules. -by-structure and molecule- by –structure.[5]

Mechanism of Action

1. Targeting chromosomes

DNA Recognition: Chromallocytes could be programmed to recognize and bind to specific DNA sequences or chromosomal regions associated with genetic disorders. This could involve using CRISPR-Cas9 technology or other targeted gene editing tools.

Cellular delivery: These nanorobots could be designed to enter cells efficiently, potentially using methods like endocytosis or by penetrating the cell membrane.

2. Repairing chromosomal abnormalities

Gene editing: Chromallocytes could deliver gene-editing enzymes like Cas9 or base editors to correct mutations or rearrangements within chromosomes. They could also carry donor DNA sequences for homologous recombination, replacing defective genes with functional ones.

Chromatin remodeling: Clottocytes could be equipped with enzymes that modify chromatin structure, enhancing accessibility to targeted genes for editing or repair.

Gene silencing: Chromallocytes could carry siRNA or other gene silencing agents to suppress the expression of harmful genes associated with chromosomal abnormalities.

3. Cellular Monitoring and Feedback

Genetic sensors: Chromallocytes could be equipped with sensors that detect the presence of specific genetic mutations or chromosomal abnormalities.

Feedback mechanisms: The detected information could trigger a response from the Chromallocyte, such as adjusting gene-editing activity or releasing signaling molecules to alert other cells or the immune system.

4. Power and Propulsion

Internal energy sources: Chromallocytes could utilize energy sources like ATP or glucose found within cells to power their functions.

Passive transport: Chromallocytes could be designed to passively diffuse within cells or move along cytoskeletal structures, leveraging natural cellular mechanisms for locomotion.

5. Biodegradability

Safe degradation: After completing their task, Chromallocytes could be designed to break down into harmless components within the cell, minimizing long-term effects.[25][26]

VI. DNA nanobots

To prevent adverse effects of DNA, nanobots are utilized to deliver the medication to the desired cell. Their goal is to create dynamic DNA nanostructures that can perform certain functions through state transitions, ranging from hybridizing and denaturing individual bases to hybridizing and denaturing entire strands. DNA origami, in which a single long strand of DNA is folded with the assistance of smaller staple strands to create the required structure, is used by DNA nanobots. To enhance illness treatment, DNA nanobots are employed as a targeted medication delivery mechanism. [5]

1. Design and Self-Assembly

DNA Strands as Building Blocks: DNA nanorobots are constructed from carefully designed sequences of DNA strands, which act as building blocks. These strands are synthesized with specific sequences that allow them to bind to each other in predictable ways.

Programmable Self-Assembly: By carefully designing the sequences of DNA strands, researchers can program them to self-assemble into complex, three-dimensional structures, creating the desired shape and functionality of the nanorobot.

Scaffolding and Folding: Often, a long, single-stranded DNA molecule acts as a scaffold, upon which shorter strands bind, folding and shaping the scaffold into the desired nanorobot structure.

2. Functionality

Targeted delivery: DNA nanorobots can be designed to carry and deliver specific drugs, proteins, or other therapeutic agents to target cells or tissues. This precise delivery mechanism can enhance treatment efficacy and minimize side effects.

Sensing and Imaging: DNA nanorobots can be equipped with sensors, such as fluorescent molecules or aptamers, to detect specific biomarkers or changes in the cellular environment. This allows for real-time monitoring of disease progression or the effectiveness of therapies.

Gene editing: DNA nanorobots can be programmed to deliver gene-editing tools, such as CRISPR-Cas9 or other gene-editing enzymes, to specific locations in the genome. This opens possibilities for treating genetic disorders or modifying cells for therapeutic purposes.

Cell manipulation: DNA nanorobots can be designed to interact with specific cells, potentially influencing their behavior or fate. They could be used to stimulate cell growth, suppress cell proliferation, or deliver targeted therapies to cells.

Microsurgical tools: DNA nanorobots could be used to perform intricate microsurgical tasks, such as clearing blockages in blood vessels or repairing damaged tissues. Their precise control and ability to interact with microscopic structures make them ideal for this purpose.

Mechanism of action

Ligand-Receptor Binding: DNA nanorobots can be designed to bind to specific receptors on the surface of cells, enabling targeted delivery or manipulation of those cells.

Enzyme activity: DNA nanorobots can carry enzymes that perform specific catalytic reactions within the cell or in the surrounding environment. These enzymes can be used to degrade harmful substances, activate therapeutic agents, or modify cellular processes.

Conformational changes: DNA nanorobots can be designed to undergo conformational changes in response to specific stimuli, such as changes in pH, temperature, or the presence of target molecules. These conformational changes can trigger the release of cargo, activate enzymatic activity, or alter the nanorobot's interaction with its environment.[27]

VII. Helices

Numerous robots with helix-like tails for movement have been created; these generally resemble the flagella of bacteria or other living things. The MOFBOTS and the MagnetoSperm described above are two examples of the majority that are better categorized as micro-sized robots.

Mechanism of action

1. Movement and Propulsion

Screw-Like motion: Helices could use their helical structure to propel themselves through fluids, much like a screw through wood. This could be particularly useful for navigating through viscous fluids like blood or mucus.

Rotation-Based movement: Helices could rotate their helical structure, creating a propulsive force that moves them forward. This could be achieved by external magnetic fields or internal mechanisms.

Targeted movement: The helical structure could be designed to respond to specific stimuli, such as chemical gradients or magnetic fields, enabling directed movement towards specific locations within the body.

2. Manipulation and Delivery

Cargo transport: Helices could act as micro-carriers, transporting drugs, genes, or other therapeutic agents to targeted locations. The helical structure could facilitate efficient loading and unloading of cargo.

Cell manipulation: Helices could be used to manipulate individual cells, potentially aiding in tissue regeneration or cell-based therapies. Their helical structure could enable them to "grab" cells or to deliver precise doses of therapeutic agents directly into cells.

Surgical precision: Helices could potentially be used for microsurgical tasks, such as clearing blockages in blood vessels or repairing damaged tissues. Their helical structure could provide a precise and controlled means of manipulating delicate structures within the body.

3. Sensing and Feedback

Environmental sensing: Helices could be equipped with sensors to detect changes in their environment, such as pH levels, temperature, or the presence of specific biomarkers.

Feedback control: The sensor data could be used to control the nanorobot's movements, allowing it to navigate towards areas of interest or respond to changing conditions.

4. Biocompatibility and Degradation

Biocompatible materials: Helices could be constructed from biocompatible materials that are safe for use within the body.

Degradable materials: Helices could be designed to degrade safely after completing their task, preventing long-term accumulation and potential toxicity.

Potential applications:

Drug delivery: Helices could deliver drugs directly to tumor sites, minimizing side effects and maximizing treatment efficacy.

Gene therapy: Helices could deliver genes to target cells for genetic therapies, potentially treating genetic disorders or enhancing immune responses.

Tissue engineering: Helices could facilitate the creation of new tissues by transporting growth factors or stimulating cell regeneration.

Diagnostics: Helices could be used to sense and report on specific biomarkers, aiding in early disease diagnosis and monitoring treatment progress.[28]

VIII. Nanorods

Typically, the nanorods are made up of cylindrical rods with various metal segments, though they can also take on diverse shapes and serve the same function. From a medical perspective, the 250 nm wide by 1800 nm long rod with gold, nickel, and gold segments created by Garcia Gradilla.

Mechanism of action

1. Nanorods as carriers for nanorobots

Nanorods as transport vehicles: Imagine nanorods acting as miniature "buses" carrying multiple smaller nanorobots to target locations. These nanorods could be engineered for specific functionalities, like targeting specific tissues or responding to external stimuli.

Delivery mechanism: The nanorods could reach the target area, then release their cargo of nanorobots. These smaller robots could then carry out their individual tasks, like delivering drugs, repairing damaged tissues, or sensing environmental changes.

Advantages: This approach could combine the advantages of both nanorods and nanorobots. Nanorods provide a stable platform for transport and increased payload, while the smaller nanorobots offer flexibility and precise action at the target site.

2. Nanorods as a component of a nanorobot

Helical nanorods: Nanorods could be incorporated into the structure of a larger nanorobot, forming a helical or other complex structure. These nanorods could contribute to the nanorobot's movement, manipulation, or sensing capabilities.

Structural Strength: Nanorods could provide structural support to the nanorobot, increasing its stability and resilience in the biological environment.

Multi-Functionality: Nanorods could be modified with specific functionalities, like binding to target cells or carrying sensors. This could allow a single nanorobot to perform multiple tasks.

3. Nanorods as a tool for nanorobotics

Manipulating nanorobots: Nanorods could be used as a tool for assembling, controlling, or manipulating other nanorobots. They could act as guides, clamps, or actuators, enabling more complex actions for the nanorobots they interact with.

External control: Nanorods could be used to control the movement or function of nanorobots by responding to external stimuli like magnetic fields or light.

Assembly and Repair: Nanorods could be used to assemble or repair other nanorobots in situ, enabling self-repairing or self-replicating systems.

4. Nanorods with intrinsic functionality

Nanorods with catalytic activity: Nanorods could be made of materials with catalytic activity, acting as miniature chemical factories within the body. They could be used to convert harmful substances into harmless ones, synthesize specific compounds, or trigger desired reactions.

Nanorods as sensors: Nanorods could be designed to act as sensors, detecting specific molecules or changes in the environment. They could then relay this information to other nanorobots or external devices for monitoring and control.

Nanorods for imaging: Nanorods could be used for imaging and diagnostics. Their unique optical properties could be exploited for fluorescence microscopy or other imaging techniques, allowing for detailed visualization of tissues or cells.[29]

Communication and Control of nanorobots

Nanobots require intricate coordination and communication to be deployed successfully. Some nanobots are designed to exchange information about their condition, task, and location as well as to speak with one another. These can collaborate easily and accomplish their objectives quickly because to this communication. certain nanobots have the ability to communicate not just with one another but also with external devices like computers or smartphones. By using this external communication, the nanobots progress may be tracked and if required, their behavior modified.[30]

Limitations

1. Using nanotechnology can be expensive and will likely continue to grow, which could put a heavy financial load on us. It is also rather challenging to manufacturer, which could contribute to the greater cost of products made using nanotechnology.
2. The hardest obstacle to overcome is the power supply. Further research is necessary to eventually enable robots to overcome the body's immunological response.
3. The conclusion that nanorobots are alien to our biology might be drawn from the fact that their existence can have disastrous effects. The body's high concentration of foreign particles makes biodegradability extremely difficult. If we depend too much on nanotechnology, our immune system might be tested, and if the nanobots can replicate, they might create a potentially dangerous version of themselves.
4. Choosing the suitable materials to create nanorobots is the biggest challenge. Although the qualities of certain materials, such as cobalt and certain earth metals, are desirable, the human body cannot tolerate them because they are harmful.
5. Since medical professionals will be using this technology to treat patients, we also need to collaborate closely with them. This implies that we must work closely with them. While it is rare for them to have irrational expectations about what we might be able to deliver, it is also possible for us to have irrational expectations about what they are truly doing. As a result, it can be difficult to bring together the medicine, the science, and the technology.
6. Drug-carrying nanorobots find it nearly impossible to move through blood arteries at the nanoscale due to the viscosity of blood. The nanorobot's behavior becomes unpredictable and uncontrollable as a result of collisions between molecules caused by the molecules' Brownian motion. One of the biggest obstacles to the research has been this instability, which is also a major one that researchers are working to overcome.

7. The creation of appropriate feedback sensors is the other major barrier, as this will allow for more precise autonomous control.[31]

CONCLUSION

The emergence of nanorobots has accompany in a new era of biomedical innovation. Their ability to navigate intricate biological environments, coupled with precise drug delivery, bio imaging, and even gene therapy capabilities, promises transformative advancements in diagnostics and treatment. The diverse array of nanorobot designs, offers a wide range of functionalities tailored to specific medical needs. Furthermore, their biodegradability and advanced control and communication systems ensure safe and effective operation. The potential applications of nanorobots extend far beyond conventional medicine, with promising uses in environmental remediation, energy production, and even nano-electronics. Despite the challenges, ongoing research and development hold immense promise for the power of nanorobots to improve human health and address global challenges.

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