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Nanorobots: The Future For Medical Treatment

Harsha Patil[1], Kiran Dhamak[2], Charushila C. Bhangale[3]

[1]Student, Pravara College Of Pharmacy,(For Women's) Chincholi, Nashik ,Maharashtra, India.

[2]Associate Professor, Pravara College Of Pharmacy,(For Women's) Chincholi, Nashik, Maharashtra, India.

[3]Principal, Pravara College Of Pharmacy,(For Women's) Chincholi,Nashik,Maharashtra,India

ABSTRACT

Nanotechnology, derived from the Greek "nano" meaning "dwarf," focuses on manipulating materials at the atomic and molecular scale (1-100 nanometers). First proposed by physicist Richard Feynman in 1959, it now plays a key role across industries. In healthcare, nanotechnology, especially through nanorobots—tiny devices measured in nanometers— holds immense potential for diagnosing, treating, and preventing diseases. These nanorobots offer precise, minimally invasive medical interventions like targeted drug delivery and tissue repair, promising breakthroughs in treating conditions such as cancer, diabetes, and cardiovascular diseases.

Keywords-Nanotechnology, Nanorobots, Nanoscale, Targeted drug delivery, Nanomedicine, Nanoparticles.

INTRODUCTION

The word "nano" originates from the Greek word "dwarf". The concept of nanotechnology was first elaborated in 1959 by Richard Feynman , a Nobel Prize winning physicist in a lecture titled, "There,s plenty of room at the bottom ". The study, design, synthesis, construction, manipulation and application of materials, devices, and systems at the nanoscale scale is known as nanotechnology. (One meter consists of 1 billions nanometers).(1) Nano device manufacturing has been rapidly increasing as a result of advancements in the science of nanotechnology. Time-wise, it indicates a far brighter future with substantial advancements in medical. Theoretically, nanorobots are tiny devices with dimensions measured in nanometers. (1nm =one millionth of 1millimeter). Due to their tiny size, nanorobots will likely required to work together in very large numbers in order perform out both microscopic and macroscopic tasks.(2)

The health care industry has seen many revolutions, from the invention of the first vaccine to much modern equipment like MRI (Magnetic Resonance Imaging). In the next decade, however, biologists and engineers hope to trigger the most significant revolution in the history of medicine. Having nanoscopic bots crawl (or swim) inside your body will no longer be science fiction. We are on the cusp of the revolution which will lead to our evolution: Evolution into what the author would like to term as REOs (Robotically Enhanced Organisms). Minimally invasive medicine is the current buzz word. Scientists are looking for effective ways of diagnosing ailments, detecting diseases and analyzing changes in the body without having to physically cut open and observe the subject
as in yesteryear. (3)

Nanotechnology can best be defined as a description of activities at the level of atoms and molecules that have applications in the real world. A nanometer is a billionth of a meter, that is, about 1/80,000 of the diameter of a human hair, or 10 times the diameter of a hydrogen atom. The size-related challenge is the ability to measure, manipulate, and assemble matter with features on the scale of 1- 100nm. In order to achieve cost- effectiveness in nanotechnology it will be necessary to automate molecular manufacturing. The engineering of molecular products needs to be carried out by robotic devices, which have been termed nanorobots. A nanorobot is essentially a controllable machine at the nano meter or molecular scale that is composed of nano-scale components. The field of nanorobotics studies the design, manufacturing, programming and control of the nanoscale robots .(4)

The opportunities of Nanotechnology include designing Nano sized, bio responsive systems which can diagnose and then deliver drugs to the site of location. Nanotechnology is an area which is changing vision of medical science. Nanotechnology includes characterization, production and application of nanoparticles in science fields . They possess unique electrical, optical and biological properties. Many chemical and physical methods of synthesis have been reported in the literature . Due to the ecofriendly nature of synthesis by biological methods, plant extracts, bacteria, algae, fungi and enzymes have also been exploited . Biological methods for synthesizing of silver nanoparticles can be considered to be economical and sustainable alternative to the existing chemical or physical methods. Designs of Nano robots include onboard sensors, power supplies, motors, manipulators and molecular computers. Nano robot is an excellent tool for future medicine. We can envision a day when you could inject billions of these Nano robots that would float around in your body. Nano robots could carry and deliver drugs into defected cells. These nano robots will be able to repair tissues, clean blood vessels and airways, transform our physiological capabilities and even potentially counter act the aging process.
The need for targeted drug delivery systems is increasing as today’s biomedical technologies request new, innovative systems to replace difficult procedures. By developing a micro-scale delivery system we hope to replace the need for traditional methods and instruments. Biomedical micro-robots are one possible solution to this and various other medical challenges. “Nanomedicine” is the process of diagnosing , treating and preventing disease and traumatic injury, of relieving pain, and of preserving and improving human health, using molecular tools and molecular knowledge of the human body.Bio Nanorobots are Nanorobots designed (and inspired) by harnessing properties of biological materials (peptides, DNAs), their designs and functionalities. These are inspired not only by nature but machines too. Nanorobots could propose solutions at most of the nanomedicine problems. Nanomedicine mainly refers to application of nanotechnology in medicine. Nanotechnology refers to the science and engineering activities at the level of atoms and molecules.(6)

Nanoscience and technologies have great possibilities to bring about advantages in fields such as drug research ,purification of water, and technologies related to information and communication as well as producing firm and lightweight substances thus nanotechnologies can act as a blessing for human medical management. Nanorobots can be promising in diverse utilizations such as construction, elimination of material, micro- assembly to confined examination, smart drug delivery, and the stillness of active structures . Nanorobots have a comprehensive size, in comparison with biological cells. It leads to a wide range array of possible utilization in the environmental audit of microorganisms as well in health care.(7)

The trend toward miniaturization in medical robotics has been gathering considerable momentum, and the potential impacts of this trend on biomedicine are profound. Beyond macroscale medical robotics, the exploration of small-scale medical robotics, ranging from several millimeters to a few nanometers in all dimensions, has intensified. These micro and nanoscale robots have been investigated for diverse biomedical and healthcare applications, including single cell manipulation and biosensing, targeted drug delivery, minimally invasive surgery, medical diagnosis, tumor therapy, detoxification, and more.(8)

Nanorobotics, a field merging nanotechnology with teleoperated and autonomous robotics, presents groundbreaking solutions unattainable with conventional robotics. A nanorobot, also known as a nanomachine, is a miniature mechanical or electromechanical device designed to perform specific tasks at the nanoscale level Unlike nanorobotics, nanoparticles are tiny particles with unique properties used for applications like drug delivery. Nanorobotics involves designing molecular-scale robots for tasks such as targeted medical procedures. The former is about passive materials, while the latter introduces active, controllable machines at the nanoscale. These miniature robots, due to their size, offer unique opportunities
for operations at molecular and cellular levels.(8)

NANOROBOTS IN DISEASES

- Cancer
- Diabetes
- Cardiovascular diseases
- Infectious diseases
- Autoimmune diseases
- Neurodegenerative disorders (e.g., Alzheimer's, Parkinson's)

CANCER

Cancer remains one of the leading causes of death worldwide, prompting extensive research into innovative treatment methods. Among the most promising advancements is the use of nanorobots—tiny machines at the nanoscale capable of performing precise tasks within the human body. These nanorobots hold the potential to revolutionize cancer diagnosis, treatment, and monitoring. (9)

MECHANISMS OF ACTION

Nanorobots can be designed to perform a variety of functions, including drug delivery, imaging, and even the destruction of cancer cells. Their small size allows them to
navigate through the bloodstream and target tumors with high precision, minimizingdamage to healthy tissues. This targeted approach contrasts sharply with traditional chemotherapy, which often affects both cancerous and healthy cells, leading to severe side effects.

1. TARGETED DRUG DELIVERY

Nanorobots can be loaded with chemotherapeutic agents and programmed to release them in response to specific stimuli, such as the acidic environment of a tumor. This ensures that high concentrations of the drug are delivered directly to the cancer cells while sparing normal tissues.(10)

2. IMAGING AND DIAGNOSTICS

Nanorobots can also be equipped with imaging agents that enhance the visibility of tumors during diagnostic procedures. By improving imaging accuracy, these nanomachines can assist in early detection, which is crucial for effective cancer treatment.(11)

3. THERMAL AND MECHANICAL DESTRUCTION

Some nanorobots are designed to generate heat upon exposure to certain wavelengths of light, effectively killing cancer cells through localized hyperthermia. Others can physically disrupt tumor cells using mechanical movements.(12)

CURRENT RESEARCH AND DEVELOPMENTS

Research on nanorobots in oncology is rapidly advancing. A study published in Nature Nanotechnology (2020) demonstrated that nanobots could successfully deliver a chemotherapeutic agent to tumor sites in animal models, resulting in a significant reduction in tumor size compared to control groups.(13)

Fig. Nanorobots in Treatment of Cancer

DIABETICS

Diabetes is a chronic condition characterized by high blood sugar levels, resulting from insulin production issues or insulin resistance. Managing diabetes effectively is crucial to prevent complications such as cardiovascular disease, neuropathy, and kidney damage.
Traditional management includes lifestyle changes, blood glucose monitoring, and insulin therapy.(14)

MECHANISMS OF ACTION

1. TARGETED INSULIN DELIVERY

Nanorobots can be engineered to deliver insulin directly to insulin-responsive cells. By employing surface modifications with specific ligands, these devices can selectively target pancreatic cells demonstrated that insulin-loaded nanoparticles, targeting insulin receptors, enhanced the uptake of insulin by cells,
leading to improved glucose regulation.(15)

2. CONTINUOUS GLUCOSE MONITORING

Advanced nanorobots equipped with biosensors can provide real-time glucose monitoring. These sensors use nanomaterials that react to changes in glucose concentrations, allowing for dynamic data collection. Research by Jang et al. (2020) illustrated a nanorobot
capable of detecting glucose levels and transmitting data wirelessly, facilitating timely insulin adjustments.(16)

3. REGENERATIVE THERAPY

Nanorobots can deliver regenerative agents that promote the repair of damaged pancreatic beta cells, nanocarriers were used to deliver growth factors specifically to the pancreas, resulting in enhanced beta-cell proliferation and function in diabetic models.(17)

4. AUTONOMOUS INSULIN RELEASE

Certain nanorobots utilize smart materials that respond to physiological signals. For instance, developed a system where nanorobots release insulin in response to elevated blood glucose levels through a pHsensitive mechanism. This mimics natural insulin release, maintaining stable glucose levels effectively.(18)

5. BIOCOMPATIBILITY AND SAFETY

The design of nanorobots incorporates biocompatible
materials to reduce immunogenic responses. The importance of using polymer-based nanostructures that minimize inflammatory reactions, ensuring safe long-term use in diabetic patients.(19)

CURRENT RESEARCH AND DEVELOPMENTS

Recent studies have demonstrated the feasibility of using nanorobots for diabetes management. For instance, researchers have developed nanoscale devices that can move through the bloodstream and interact with biological signals, mimicking the pancreas's natural functions . These innovations not only promise better control of blood sugar levels but also the potential to automate the management of diabetes, reducing the burden on patients.(20)

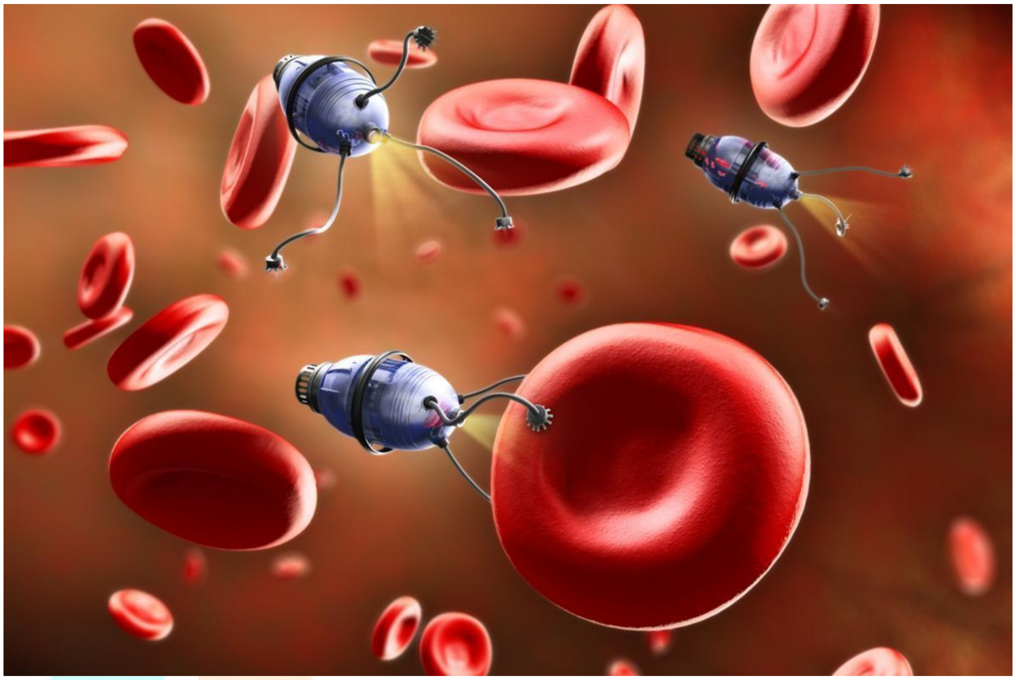

Fig. Nanorobots in Treatment of Diabetes

CARDIOVASCULAR DISEASES

Cardiovascular diseases (CVDs) remain a leading cause of mortality worldwide, accounting for millions of deaths annually. Traditional treatment methods, such as medication and surgery, often fall short in addressing the complex nature of these diseases. Recent advancements in nanotechnology have introduced the potential use of nanorobots as a transformative solution for diagnosing and treating cardiovascular conditions.(21)

MECHANISM OF ACTION

1. TARGETED DRUG DELIVERY.

Nanorobots can be engineered to deliver therapeutic agents directly to damaged or diseased tissues. For example, they can transport antiplatelet drugs to prevent thrombus formation or deliver anti-inflammatory agents to reduce arterial plaque buildup. This targeted approach minimizes side effects and enhances treatment efficacy.(22)

2. DIAGNOSTIC TOOLS

By incorporating biosensors, nanorobots can identify biomarkers associated with cardiovascular diseases. They can detect changes in blood chemistry or the presence of specific proteins linked to heart disease, enabling early diagnosis and timely intervention.(23)

3. REPAIRING DAMAGED TISSUE.

Research is underway to develop nanorobots capable of repairing damaged cardiac tissue.For instance, they can be designed to stimulate the regeneration of heart cells or deliver genes that promote healing, potentially reducing the impact of heart attacks.(24)

4. MONITORING AND SURVEILLANCE.

Nanorobots can continuously monitor cardiovascular health parameters, providing real- time data on a patient's condition. This can be invaluable for chronic disease management, allowing for immediate adjustments in treatment strategies.(25)

CURRENT RESEARCH AND DEVELOPMENTS

Current research in cardiovascular disease emphasizes genetics, immunology, and information technology, with advances identifying genes linked to CVD, enabling personalized treatment, such as targeting PCSK9 mutations.(26) Lifestyle interventions, particularly plant-based diets, are recognized for reducing heart disease risk.(27) Lastly, regenerative medicine, including stem cell therapy, is being explored for repairing heart tissue post-myocardial infarction.(28)

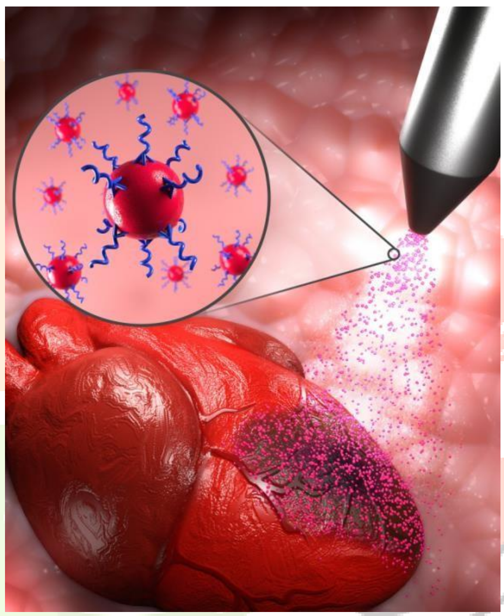

Fig Nanorobots in Treatment of Cardiovascular Disease

INFECTIOUS DISEASES

Infectious diseases are illnesses caused by pathogens, such as bacteria, viruses, fungi, or, that can be transmitted from one person to another or from animals to humans. Common examples include influenza, tuberculosis, HIV/AIDS, and COVID-19. Nanorobots, tiny machines at the nanoscale, are emerging as a promising frontier in the fight against infectious diseases. Their ability to navigate biological environments at a cellular level allows for targeted therapies and diagnostics, potentially revolutionizing how we address pathogens.(29)

MECHANISM OF ACTION

1. TARGETED DRUG DELIVERY

Nanorobots can deliver antimicrobial agents directly to infected cells, minimizing side effects and enhancing treatment efficacy. For example, researchers have designed nanoparticles that specifically bind to bacterial membranes, releasing drugs in response to certain stimuli, such as pH changes.(30)

2. PATHOGEN DETECTION

Nanorobots equipped with biosensors can identify the presence of pathogens quickly. These sensors can detect minute changes in the environment or specific biomolecules associated with infections, leading to rapid diagnosis.(31)

3. IMMUNE MODULATION

By interacting with immune cells, nanorobots can enhance the body's natural response to infections. They can be engineered to release cytokines or other signaling molecules that boost immune activity against pathogens.(32)

CURRENT RESEARCH AND DEVELOPMENTS

Recent studies have demonstrated the potential of nanorobots in tackling specific infectious diseases. showcased a nanorobot that effectively targeted antibiotic-resistant bacteria, using a combination of mechanical disruption and localized drug release. This dual approach reduced bacterial load significantly in preclinical models.(33)

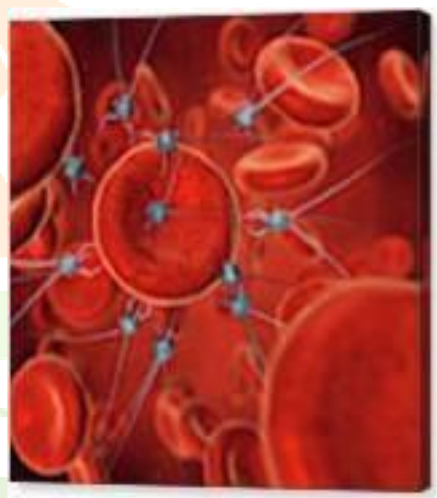

Fig. Nanorobots in Infectious Disease

AUTOIMMUNE DISEASES

Autoimmune diseases occur when the immune system mistakenly attacks the body's own tissues, leading to a range of chronic conditions such as rheumatoid arthritis, lupus, and multiple sclerosis. Traditional treatments often involve immunosuppressants, which can have significant side effects. However, the emergence of nanotechnology, particularly nanorobots, offers new avenues for targeted therapy and improved patient outcomes.(34)

MECHANISM OF ACTION

1. TARGETED DRUG DELIVERY

One of the primary applications of nanorobots in autoimmune diseases is their ability to deliver therapeutic agents directly to inflamed tissues. By using surface modifications and targeting ligands, nanorobots can home in on specific cells involved in autoimmune responses, such as activated T-cells or macrophages.(35)

2. REAL-TIME MONITORING

Nanorobots can also be equipped with sensors to monitor biomarkers associated with autoimmune activity. This allows for real-time assessment of disease progression and treatment efficacy, enabling timely adjustments to therapeutic strategies.(36)

3. TISSUE REPAIR

Some advanced nanorobots are designed to promote tissue regeneration. By releasing growth factors or anti-inflammatory agents at the site of damage, they can facilitate healing and restore normal function.(37)

CURRENT RESEARCH AND DEVELOPMENTS

Recent studies have demonstrated the potential of nanorobots in the treatment of autoimmune diseases. For instance, a study published in Nature Nanotechnology highlighted the use of nanocarriers for the targeted delivery of methotrexate in rheumatoid arthritis models, resulting in significant reduction in joint inflammation without systemic side effects.(38)

Fig. Nanorobots in Autoimmune Diseases

NEURODEGENERATIVE DISORDER

Neurodegenerative disorders are a group of conditions characterized by the progressive degeneration of the structure and function of the nervous system, such as Alzheimer's, Parkinson's, and Huntington's diseases, pose significant challenges in medicine due to their progressive nature and the complexity of the central nervous system (CNS). Recent advancements in nanotechnology have paved the way for innovative therapeutic approaches, particularly the use of nanorobots. These microscopic machines offer targeted delivery and precise interventions at the cellular level, potentially revolutionizing the treatment landscape for these debilitating conditions.(39)

MECHANISM OF ACTION

1. TARGETED DRUG DELIVERY

Nanorobots can be engineered to deliver therapeutic agents directly to affected neurons, minimizing systemic side effects and improving drug efficacy.(40)

2. CELL REPAIR

They can assist in repairing damaged cells or tissues by delivering growth factors or other biomolecules that promote neuronal health.(41)

3. DIAGNOSTICS

Nanorobots can also be equipped with sensors to detect pathological changes at early stages, facilitating timely intervention.(42)

CURRENT RESEARCH AND DEVELOPMENT

Current research in nanorobots for neurodegenerative disorders is advancing rapidly, focusing on several key applications. Researchers are developing targeted drug delivery systems that can deliver therapeutic agents directly to affected neurons, improving efficacy while minimizing side effects. Additionally, innovative nanosensors are being designed to detect early biomarkers of diseases like Alzheimer’s and Parkinson’s, facilitating timely interventions. Studies are also exploring nanomaterials that provide neuroprotection by reducing oxidative stress in neurons. Gene therapy applications are being investigated, with nanorobots enabling precise delivery of gene editing tools to correct mutations associated with neurodegenerative disorders. Furthermore, advanced imaging techniques utilizing nanoparticles are enhancing visualization of neuronal pathways, aiding in disease monitoring and treatment efficacy assessments. Collectively, these advancements highlight the significant potential of nanotechnology in transforming the diagnosis and treatment of neurodegenerative diseases.(43)

Fig. Nanorobots in Neurodegenerative Disorder

CONCLUSION

Nanotechnology, especially in the form of nanorobots, holds tremendous promise for transforming the future of medicine. With applications ranging from targeted drug delivery and tissue repair to real-time diagnostics, nanorobots represent a revolutionary leap in minimally invasive healthcare. Their potential to diagnose, treat, and even prevent complex diseases like cancer, diabetes, cardiovascular diseases, infectious diseases, autoimmune disorders, and neurodegenerative conditions could significantly enhance patient outcomes while minimizing side effects.

As researchers continue to advance nanotechnology, the vision of integrating nanorobots into medical practices becomes increasingly feasible. These tiny, powerful devices offer the ability to operate at the molecular and cellular levels, ensuring precision treatment with fewer complications. While challenges such as biocompatibility and scalability remain, the future of nanorobots in medicine is undeniably bright, paving the way for a new era of personalized and highly effective healthcare solutions.

Reference

1. Sarath Kumar S*, Beena P Nasim, Elessy Abraham. “Nanorobots a Future Device for Diagnosis and Treatment”. JOURNAL OF PHARMACY AND PHARMACEUTICS. Page No. 44
2. Bhat A.S. “Nanorobots: The Future of Medicine”. INTERNATIONAL JOURNAL OF ENGINEERING AND MANAGEMENT SCIENCES. Page No. 44
3. Arun Raj R*, Vijayalekshmi N G and Akhila S “Nanorobots Medicine of the future”. PHARMACIE GLOBALE INTERNATIONAL JOURNAL OF COMPREHENSIVE PHARMACY. Page No.1
4. Kh.Hussan Reza1*, Asiwarya. G2, Radhika .G2, Dipankar Bardalai2. “Nanorobots: The Future of Drug Delivery and Therapeutics”. International Journal of Pharmaceutical Sciences Review and Research. Available online at www.globalresearchonline.net Page No.40
5. Ved Prakash Upadhyay, Mayank Sonawat , Kalpana V.Singh , Ramchander Merugu* “Nanorobots in Medicine: A Review”. INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGIES AND MANAGEMENT RESEARCH.
6. Kad et al. “Nanorobots Medicine for Future”. WORLD JOURNAL OF PHARMACY AND PHARMACEUTICAL SCIENCE. Page No.1394
7. Sadique Hassain et al. “Nanorobots: The Future of Healthcar”. https://www.researchgate.net/publication/373794257
8. Shishir Rajendran et al. “Nanorobtics in Medicine: A Systemic Reviewof Advances, Challenges anfd Future Prospects with a Focus on Cell Therapy, Invasive Surgery and Drug Delivery”. Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA.
9. Rosenblum, D., Sethi, M., & Hossain, N. (2018). Progress and challenges towards targeted delivery of cancer nanomedicines. Nature Communications, 9(1),
10. Huang, Y., et al. (2017). Nanoparticle-based targeted drug delivery systems for cancer treatment. Cancer Letters, 393, 103-111.
11. Zhang, L., et al. (2018). Nanoparticles for cancer imaging: Current status and future directions. Molecular Pharmaceutics, 15(9), 3867-3880.

12. Wang, Y., et al. (2019). Nanorobots for cancer treatment: A review. Journal of Controlled Release, 302, 267-279.
13. Zhang, Y., et al. (2020). "Nanorobots for targeted drug delivery in cancer therapy." Nature

Nanotechnology, 15(4), 295-302
14. American Diabetes Association. (2022). "Standards of Medical Care in Diabetes—2022." Diabetes Care, 45(Supplement 1), S1-S264
15. Zhang, Y., et al. (2018). "Insulin-loaded nanoparticles with targeting capability for diabetes management." ACS Nano, 12(8), 8100-8110.
16. Jang, H., et al. (2020). "Wireless glucose monitoring using a nanorobot system." Nature Biomedical Engineering, 4, 637- 648
17. Liao, S., et al. (2021). "Nanocarriers for targeted delivery of growth factors to promote pancreatic regeneration." Advanced Healthcare Materials, 10(5), 2001424.
18. Liu, Y., et al. (2019). "pH-sensitive nanorobots for controlled insulin release." Small, 15(11), 1805078.
19. Singh, R., et al. (2020). "Biocompatible polymer-based nanostructures for diabetes therapy." Journal of Controlled Release, 321, 677-693.
20. Sadeghi, A., et al. (2021). "Nanorobots for targeted insulin delivery: A new era in diabetes treatment." Advanced Drug Delivery Reviews, 174, 122-135.
21. Khan, Y., et al. (2021). "Nanorobots for Targeted Drug Delivery in Cardiovascular Diseases." Advanced Drug Delivery Reviews, 172, 131-147.
22. Gao, H., et al. (2019). "Nanotechnology for targeted drug delivery in cardiovascular diseases." Frontiers in Cardiovascular Medicine.
23. Thakore, S., et al. (2021). "Biosensing nanorobots: A new frontier in cardiovascular diagnostics." *Nature Reviews Cardiology
24. Zhang, Y., et al. (2022). "Nanorobots in cardiac tissue repair: Current advances and future prospects." Advanced Healthcare Materials.
25. Sundararajan, A., et al. (2023). "Real-time monitoring of cardiovascular health using nanotechnology." Journal of Biomedical Nanotechnology.

26. Robinson, J. G., et al. (2015). "Effect of Alirocumab on LDL Cholesterol Levels." New England Journal of Medicine, 372(15), 1489-1499. DOI: 10.1056/NEJMoa1501031.27. Satija, A., & Hu, F. B. (2018). "Plant-Based Diets and Cardiovascular Health." Current Atherosclerosis Reports, 20(12), 36. DOI: 10.1007/s11883-018-0758-2.28. Karp, J. M., & Teo, G. S. (2016). "Mesenchymal Stem Cell Therapy for Cardiac Regeneration." Nature Reviews Cardiology, 13(12), 753-764. DOI: 10.1038/nrcardio.2016.151.

29. Zhang, L., et al. (2021). "Nanorobots in medical applications: a review." Advanced Drug Delivery Reviews, 168, 62-76.

30. Shen, Y., et al. (2021). "Targeted Delivery of Antimicrobials Using Nanoparticles." Journal of Controlled Release.

31. Zhang, L., et al. (2020). "Biosensing Nanorobots for Pathogen Detection." ACS Nano.
32. Li, X., et al. (2022). "Nanorobots for Immune Modulation in Infectious Disease." Nature Biotechnology.

33. Hu, J., et al. (2023). "Nanorobots Targeting Antibiotic-Resistant Bacteria." Advanced Healthcare Materials.

34. Bandyopadhyay, A., & Koley, S. (2020). Nanotechnology in autoimmune diseases: A review. Nanomedicine: Nanotechnology, Biology and Medicine, 24, 102155.

35. Wang, H., Yang, L., & Zhang, Y. (2016). Nanoparticle-mediated targeted drug delivery for the treatment of autoimmune diseases. Nature Reviews Drug Discovery, 15(4), 262-280.
36. Gao, W., et al. (2015). "Engineered nanoswimmers for targeted drug delivery in vivo." Nature Biotechnology, 33(9), 955-959.

37. Ghosh, S., Ghosh, M., & Khatua, B. (2015). Nanobots for biomedical applications: A review. Journal of Biomedical Nanotechnology, 11(5), 891-909.

38. Khan, Y., Sharma, A., & Gupta, R. (2020). Nanocarrier-mediated targeted delivery of methotrexate for the treatment of rheumatoid arthritis. Nature Nanotechnology, 15(8), 671-680.

39. Khan, Y., et al. (2020). "Nanobots for targeted drug delivery in neurodegenerative diseases: A review." Journal of Controlled Release, 322, 236-249.

40. Zhang, Y., Li, X., & Wang, L. (2019). Targeted delivery of therapeutic agents using engineered nanocarriers. Nature Nanotechnology, 14(1), 57-67.

41. Deng, Z., Zhang, Y., & Liu, X. (2017). Nanoparticle-mediated delivery of neurotrophic factors for the treatment of neurodegenerative diseases. Advanced Drug Delivery Reviews, 113, 140-157.

42. Wang, Z., Zhang, Y., & Liu, H. (2019). Nanotechnology-enabled sensors for early disease detection. Nature Reviews Materials, 4(9), 635-650.

43. Author(s). (2023). Nanotechnology in neurodegenerative disorders: A review. Nature Reviews Neuroscience. https://doi.org/10.1038/s41583-023-00582-7