COMPREHENDING NANOTECHNOLOGY: A GUIDE TO NANOMEDICINE

Abstract

Nanotechnology is regarded as a most promising technology of 21st century which helps to bridge the technological gaps between chemistry, physics & biology in nanoscale, this revolutionary technology has been applied in many scientific areas through an integrated approach. Nanotechnology or nanotech encircle a understanding and manage matter on a atomic, subatomic, molecular and supra molecular scale.

Many researchers have considered nanotech as a novel technique in medical research since it has a extensive application in the field of medicine, the application of nanotech for medical purpose is been termed as nanomedicine. An increasing number of applications of nanomedicine include development of new drug substances, various nanoparticles are used in diagnostic instruments, methodologies, tissue engineering, imagery, biomedical implants, targeted medicinal products, pharmaceutical products, used in MRI, Ultrasound where precised light is passed to the concern region to heat it at 131ºF which destroys the tumor cells, Nanorobots such as Gold "Nano shells" are useful in the fight against cancer, other applications such as Neuron replacement, removal of kidney or liver stones, cure skin diseases, smart anti-cancer therapeutics.

Nanotechnology have various advantages, it function at atomic and molecular level known as molecular manufacturing to build machines, circuits or devices for industries. Nanobots are able to replicate themselves to replace damage tissue etc.

Keywords: Nano-Medicine, Nano particles, Nano robots, Nanotechnology, MRI, Ultrasound, Nanobots, Targeted medicine, Drug delivery, Nano science, Cancer treatment, Blood Clot, Quantum Dots, Dendrimers, Liposomes, Metal Nano particles, Carbon nanotubes, Precision medicine, Gold particles.

Authors

Ms. Sashisaroj T Tiwari
Assistant Professor
Department of Radiology
School of Paramedics and Allied Health Sciences
Centurion University of Technology and Management
Odisha, India.

I. INTRODUCTION

The utilization of nanotechnology in the development of innovative medicines is emerging as a significant area of research investigation. Furthermore, apart from their utility in the creation of innovative methodologies, Nanotechnology possesses the potential to augment traditional techniques [1-2].It is important to differentiate between the fields of Nanotechnology & Nanoscience. Nanoscience pertains to investigation of structures & molecules at Nano scale, which ranges from 1 to 100 nm. On the other hand, nanotechnology refers to the practical applications of Nano science, such as the development of devices and other related technologies. Nanotechnology is been recognized as a key enabling technology, that possesses the ability to introduce innovative and inventive medical remedies to effectively address deficiencies in the healthcare industry. [3-4]. The dimensions of nanomaterial's range from 10 nm to 100 nm & their substantial surface area renders them as an appealing substance intended for utilization in biological contexts. The size of nanoparticles are smaller than that of the blood cells and nearly equivalent in size to DNA, which affords them superior performance and unique physical, optical & chemical properties which enable their utilization in the medical field for treatment and diagnosis These Nano materials possess the ability to traverse through various organs within the body and effectively penetrate targeted tissues. By conjugating drug molecules with nanoparticles, abnormal tissues such as cancer cells can be subjected to targeting for the purpose of diagnostics. [1, 2, 5]. Several types of nanoparticles have been utilized for identification and visualization of cancer through medical imaging techniques. due to their diverse biological applications. [6] These Nano materials possess unique, optical, chemical & magnetic characteristics that enable that facilitate the creation of imaging probes with exceptional contrast, heightened sensitivity, regulated bio distribution, and enhanced spatial imaging in USG, MRI, and SPECT& PET Techniques [7].

The utilization of nanotechnology has been implemented to augment immune responses towards antigens for efficacious vaccination, to administer pharmaceuticals to a precise location and dispense them at a regulated pace, and to precisely and expeditiously detect and identify ailments at a reduced expense. These applications demonstrate the potential of nano materials in various medical fields [8] thus nanomaterial's have the ability to overcome limitations in traditional therapeutic and diagnostic agents. They are increasingly being used in medicine and pharmaceuticals, offering excellent prospects.

II. HISTORY

The term 'nano' is derived from the Greek prefix 'dwarf' and denotes a minute size of one thousand millionth of a meter (10^{-9} m). The notion of nanotechnology was first introduced by the distinguished American physicist and Nobel Prize recipient, Richard Feynman in year 1959. This seminal event took place at the annual gathering of the American Physical Society, where Feynman delivered a lecture entitled "There's Plenty of Room at the Bottom" at the esteemed California Institute of Technology (Caltech).he is considered the father of modern nanotechnology. [9]. The term "nanotechnology" was introduced and established by Norio Taniguchi, a Japanese scientist, in 1974, following a period of fifteen years. Taniguchi's definition of nanotechnology highlights its primary focus on the manipulation of materials through the actions of a single atom or molecule, which encompasses various processes such as separation, consolidation, and deformation [10] The term "nanomedicine" was introduced in 1999, coinciding with the publication of Nanomedicine: Basic Capabilities, the first of two volumes authored by American scientist Robert A. Freitas Jr. on the subject [11]

III. NANOMEDICINE

The use of nanotech for medical purpose is been termed as Nanomedicine. It's an interdisciplinary field of science. The European Science foundation (ESF) have defined Nanomedicine as, the discipline of utilizing molecular tools & knowledge to diagnose, treat, and prevent diseases and traumatic injuries, alleviate pain, and enhance human.

The overarching objective of Nanomedicine is to achieve comprehensive monitoring, defense, repair, construction, control, and enhancement of all human biological systems, operating at the molecular level through the utilization of engineered devices and nanostructures, with the ultimate goal of realizing medical benefits.

Nanomedicine possesses extensive applications in the field of medicine and is therefore regarded as a groundbreaking solution for bridging gaps in healthcare. These applications are made feasible through the utilization of nanoparticles or Nano robots [11].

IV. NANOPARTICLES

Nano particles are characterized as particles of matter that possess a diameter ranging from 1 to 100 nanometers (nm). They are broadly classified into 3 categories based on their structural makeup [**Figure 1**] such as organic type, inorganic type and carbon based nanoparticles [12-13].

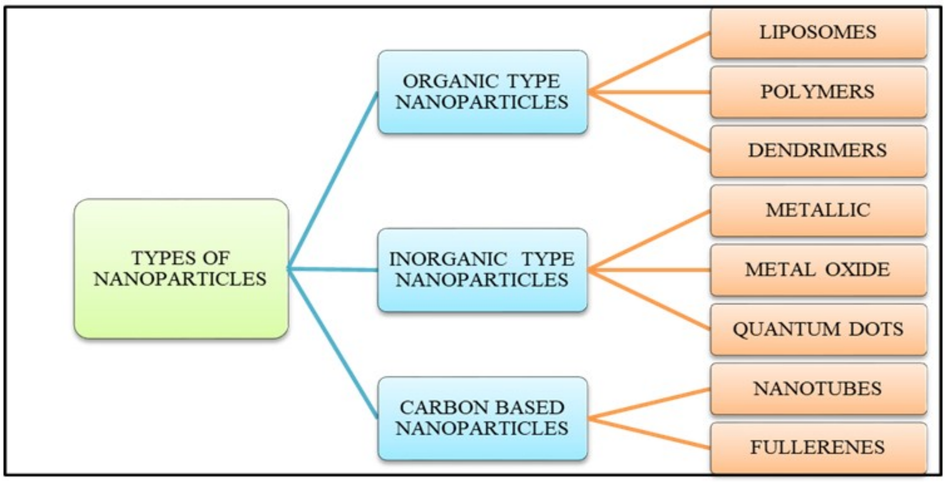

Figure 1: Types of Nanoparticles

1. **Organic Type:** made up of organic compounds those are converted to organic nanomaterial. E.g. Liposomes, Dendrimers, Polymers etc.

   - **Liposomes**- they are diminutive, spherical vesicles that contain lipid bilayers encasing an aqueous inner phase **(Figure 2)**. Typically, these nanoparticles are comprised of cholesterol or phospholipids and are utilized to encapsulate various active drugs. Upon reaching the intended site, they merge with the cell membrane and release the molecules, thus they are useful in targeted drug delivery and cancer treatment [13].

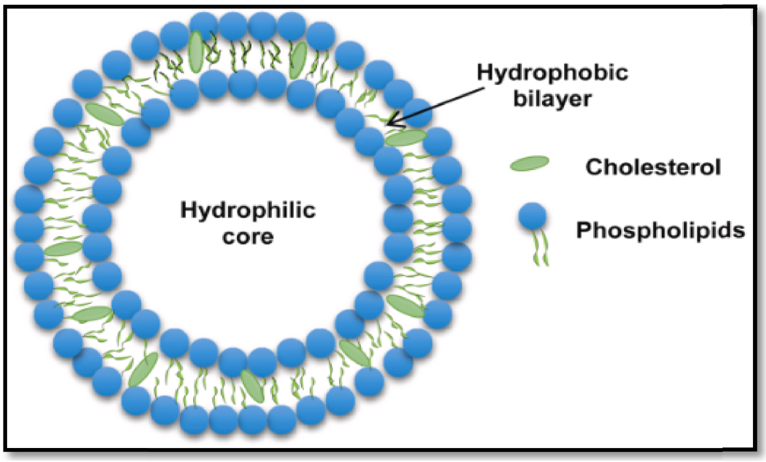

Figure 2: Structure of Liposome
(**Source: Nsairat** H, Khater D, Sayed U, Odeh F, Al Bawab A, Alshaer W. Liposomes: structure, composition, types, and clinical applications. Heliyon. 2022 May 13;8(5):e09394.) [37]

- **Dendrimers:** These are artificial macromolecules with 3D network containing a high number of functional groups measuring 2-20nm. They have 3 layers namely, the inner layer, the molecular core (site for branching), & outer layer **(Figure 3)**. Additionally they has properties such as viscosity, micellar and solubility. That make them useful for drug delivery or gene therapy, they are also used as antibacterial, antifungal, and anticancer agent [15,16].

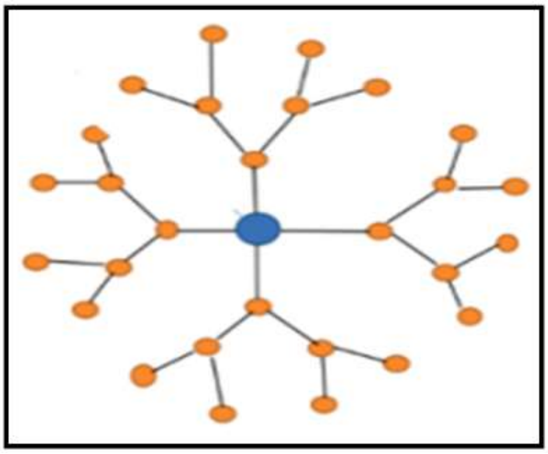

Figure 3: Structure of Dendrimers
(**Source:** Alrushaid, N.; Khan, F.A.; Al-Suhaimi, E.A.; Elaissari, A. Nanotechnology in Cancer Diagnosis and Treatment. Pharmaceutics 2023, 15, 1025. https://doi.org/10.3390/ pharmaceutics15031025) [19]

2. **Inorganic Type**: These nanomaterial's lack carbon atoms in them. They are classified into metal-based, metal oxide-based and quantum dots.

   - **Metallic** - These nanoparticles have an ability to combine and form substantial structures due to large amount of energy on the surfaces. Gold (Au), cadmium (Cd), aluminum (Al), iron (Fe), zinc (Zn), cobalt (Co), copper (Cu), lead (Pb), & silver (Ag), these Metallic substances are commonly employed in the synthesis of nanoparticles. Metal nanoparticles have excellent UV sensitivity, thermal, electrical, catalytic, and antibacterial properties. Metallic nanoparticles are of 4 type's metallic Nano platelets, metallic nanowires, metallic nanoparticles, and metallic nanostructures [14].

   - **Quantum Dots** – QDs are minute crystals of nanoscale, which act as an electron transporter, QDs emit light in a multitude of colors with a significantly high level of energy under UV light exposure. These QDs are useful for fluorescent biological labels [17, 18].

   - **Metal Oxides** – They are composed of negative oxygen ions and positive metallic ions. E.g. Silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3), Titanium oxide (TiO_2) etc. which are used in electro-analysis for biomolecules detection [14].

3. **Carbon based**: They are extensive family of carbon allotropes, which consist of 0D fullerenes, 1D carbon nanotubes (CNTs), 2D Graphene, and 3D Nanodiamonds & Nano horns.

   - **Nanotubes** – Carbon nanotubes are hexagonal shaped arrangements of carbon atom made of single/ or double wall carbon that are rolled into long tubes (**(Figure 4)** MWCNT – Multiple Wall Carbon Nanotube, SWCNT: Single Wall Carbon Nanotube). They have broad range of durability, thermal conductivity, electrical and lightweight properties. They are further classified as single walled nanotubes (SWNTs), and multi walled nanotubes (MWNTs).they find their application in hydrogen storage, biosensors, electronic nanodevices, and touch screens etc. [19, 21]

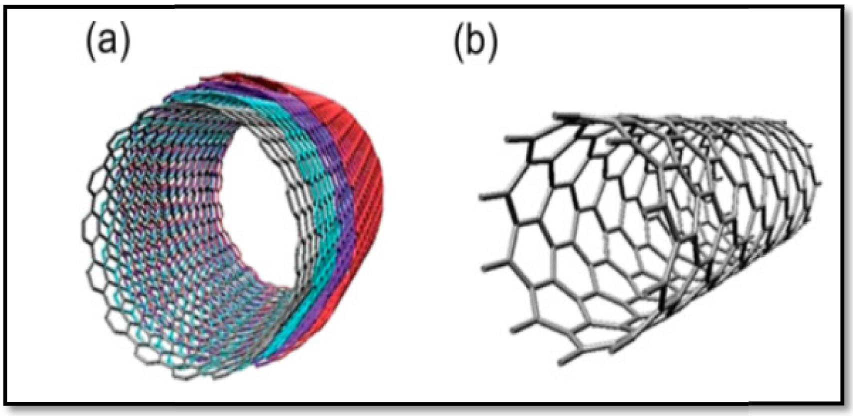

Figure 3. Structure of Carbon Nanotubes A) MWCNT B) SWCNT
(**Source:** T. Maruyamam,Carbon nanotubes, Handb.Carbon-Based Nanomater.Micro Nano Technol.(2021)) [38]

- **Fullerene** – It is an allotrope of carbon, belonging to Buckminsterfullerene family **(Figure 5)**. Fullerenes are utilized in various chemical applications for successful drug delivery where drug molecules get entrapped in the fullerene mesh due to their mesh-like structure. Fullerene comprises interconnected carbon atoms bonded by single or double bonds [19, 20]

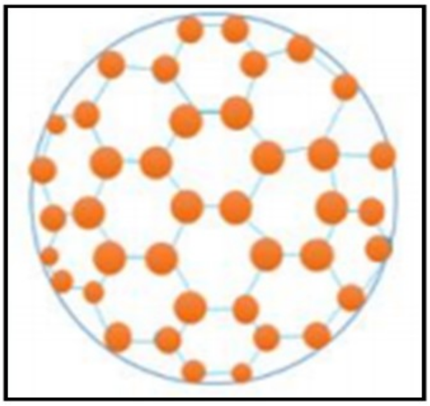

Figure 5: Structure of Fullerene
(**Source**: Alrushaid, N.; Khan, F.A.; Al-Suhaimi, E.A.; Elaissari, A. Nanotechnology in Cancer Diagnosis and Treatment. *Pharmaceutics* **2023**, *15*, 1025. https://doi.org/10.3390/ pharmaceutics15031025) [19]

V. NANOROBOTS

Tiny machines used to cure or diagnose a disease in humans or in any organism. They perform a task at a Nanoscale [9-10].

1. Design and Working [22]**:** The various components in nanorobots include:

- **Molecular sorting motor:** This is a type of nanomechanical device that exhibits the ability to selectively bind and release molecules from solutions, as well as transport these molecules against significant concentration gradients. The device is composed of carbon nanotubes
- **Propellers:** It's employed to propel forward against the flow of blood
- **Fins**: The device is equipped with propellers and it's a surface that serves the purpose of providing stability, generating lift and thrust, or facilitating steering while in motion through water, air, or other fluid media.
- **Sensors:** It is fitted internally & externally with nanorobot to obtain the directional movement signal. They are also called as detectors it's a device that quantifies a physical parameter & transforms it into a signal that can be interpreted by an observer or electronic equipment.
- **Payload:** Is the void section that holds a small dosage of medication or drug that is utilized to traverse the bloodstream and deliver the medication to the site of infection or injury.
- **Micro camera:** It is a miniature camera that serves as a means to operate and direct the nanorobot during manual navigation within the body

- **Electrodes:** The electrodes function as a battery by utilizing the electrolytes present in the bloodstream. Additionally, its capable of eradicating cancer cells through the generation of an electric current, which results in the heating and subsequent destruction of the malignant cells.
- **Lasers:** It's used to destroy the harmful materials like, blood clots, arterial plaque or cancer cells.
- **Ultrasonic signal generators:** The nanorobots employ these generators to selectively target and eliminate renal calculi
- **Swimming Tail:** It provides a means for propulsion for the nanorobot to get inside the body as they travel against blood flow.

2. **Powering and Navigation of Nanorobots:** Nanotechnology uses both external and internal power sources. There are different types of nanorobots classified based on their size & shapes **(Figure 6).** Some nanorobots are designed to use patients body as a medium to generate power, others contain small power source on the surface of the robots itself.

   Nanorobots can get the power directly from the bloodstream or generate chemical reactions utilizing blood as fuel source for energy production. Nanorobots can also utilizes body heat of patient to create power; the power generation is a result of seebeck effect (A phenomenon that arises from the junction of two dissimilar conductors at two distinct temperatures). The metallic conductors exhibit thermocouple behavior, wherein they generate a voltage when their junctions are subjected to different temperatures.

VI. APPLICATION OF NANOTECHNOLOGY

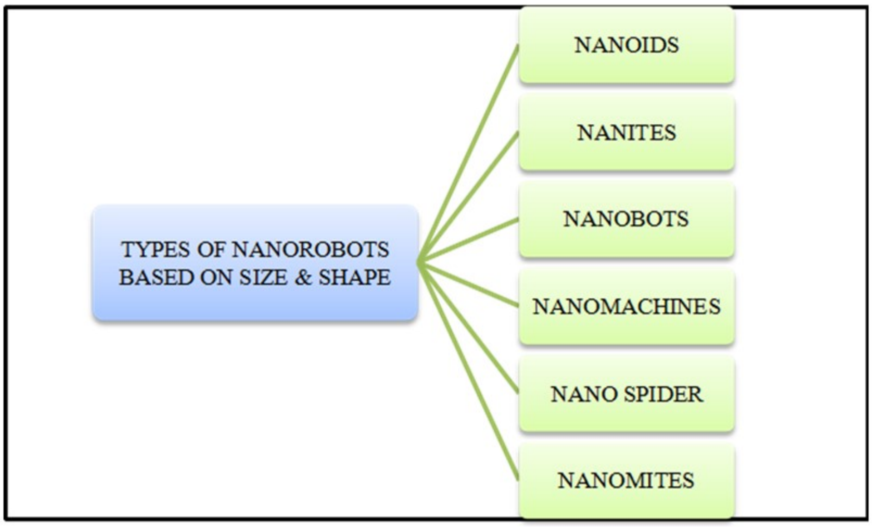

Figure 6: Classification of Nanorobots Based on Size and Shape

Nanomedicine finds its application in diverse domains of medicine including,

- Diagnostic
- Therapeutic
- Immunization and Vaccine Production.

The applications of nanotechnology in healthcare industry are as follows **(figure 7)**:

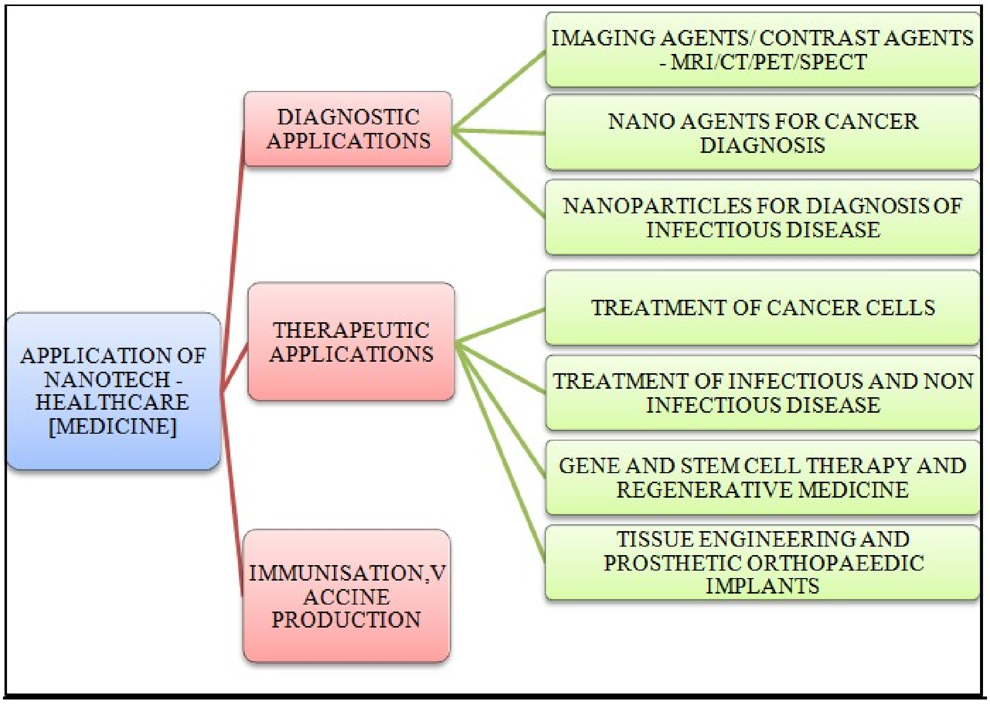

Figure 7: Application of Nanotechnology in Healthcare

1. **Diagnosis and Treatment of Cancer:** These nanorobots contains a chemical biosensors for detecting the tumor cells in early stages of cancer development within a patient‘s body. These sensors search the intensity of E-cadherin signals [23]. Different metallic nanoparticles are more sensitive in detecting tumor cells since they can combine with the cancer specific antibodies and penetrates the cancerous cell more easily [19, 24]. Nanocomposites that contain multiple variation of nanoparticle such as platinum, copper, silver, gold and cobalt are more effective in detecting cancer cells. Nanomaterial’s of various kinds have demonstrated encouraging outcomes in clinical scenarios. To transport anticancer drugs to the specific location in cancer tissues securely and efficiently, nanomaterial’s are usually linked with anticancer drugs [19].

2. **Removal of Kidney Stone:** Nanorobots are equipped with ultrasonic signal generators that enable them to precisely target and administer sonic frequencies to the kidney stone, resulting in its destruction [23].

3. **Destruction of Blood Clot / Removal of Arteriosclerosis:** Nano polymers, such as Polyvinyl Alcohol, have the potential to serve as a coating material for implantable devices which come into contact with blood, such as vascular grafts, artificial hearts, and catheters. This coating can be utilized to disperse clots or prevent their formation. Nanorobots can be used to treat conditions like arteriosclerosis by employing a manual process of removing the plaque adhered to the inner lining of the artery wall. Lasers/ special blades (activated by continuous or single pulse) present in the Nanobots used to destroy the harmful materials like arterial plaque, blood clots or cancer cells [23].

4. **Tissue Repair and Replacement/Gene Therapy:** The advancement of bio mimetic scaffolds featuring nanostructures has been shown to augment migration, cellular proliferation, & homing effects through the emulation of the natural bone hierarchy and extracellular matrix. This promotes regeneration of injured tissues [25, 26]. Nano particle-based targeted labeling technology has enabled rapid assessment of bone quality & identification of early cartilage defects [25, 27]. Nano particles and extracellular vesicles which is employed as drug delivery vehicles, allow for minimized dosage, increased half-time thereby attaining targeted therapy for diverse forms of osteochondral lesions. Bio-compatible nanomaterial's increase the adhesion, durability, and life span of implants [25].

5. **Diabetes Monitoring:** The Nanorobots contain Nano biosensors to monitor blood glucose levels. These sensors transmit the information through RF Signal to the mobile phones of patients regarding their blood glucose level once every two hours.

Other Applications

1. **Drug Delivery:** Nano-scale drug delivery systems (nano-DDS) like Metal based nanoparticles (e.g. Gold, Silver, Cd-Se etc.), Lipid based nanoparticles (Liposome & Neosomes), Polymer based Dendrimers, Chitosan and Biological nanoparticles like arginylglcylaspartic acid (RGD) peptides are widely used for the purpose of drug delivery. This are quite stable and helps in controlled and targeted drug release thus reducing side effects and increasing patient safety **(Figure 8)**.

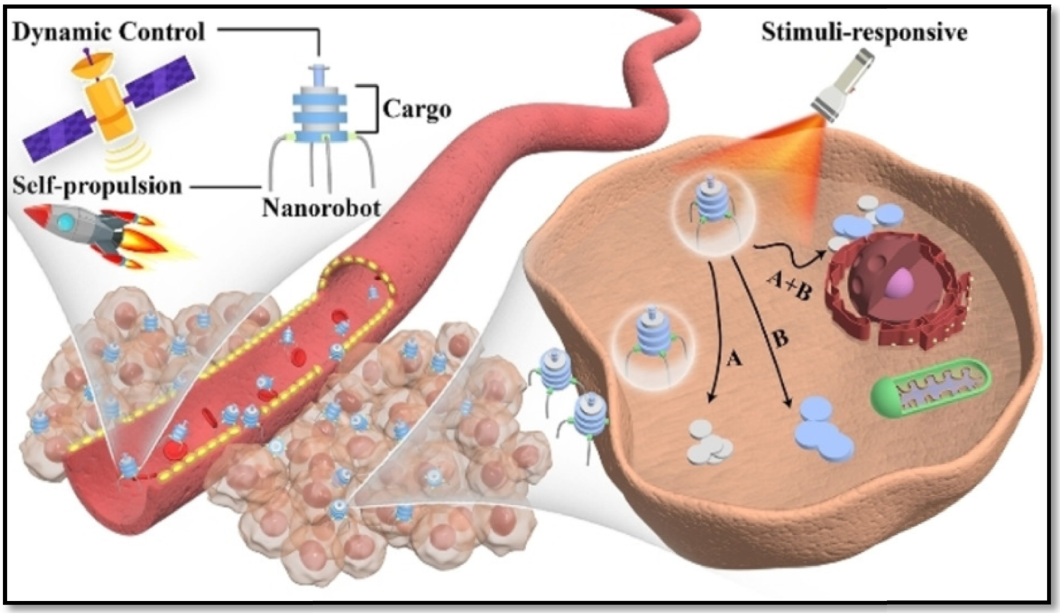

Figure 8: Targeted drug delivery
(**Source:**L. Huang, F. Chen, Y. Lai, Z. Xu, H. Yu, *ChemBioChem***2021**, *22*, 3369.) [39]

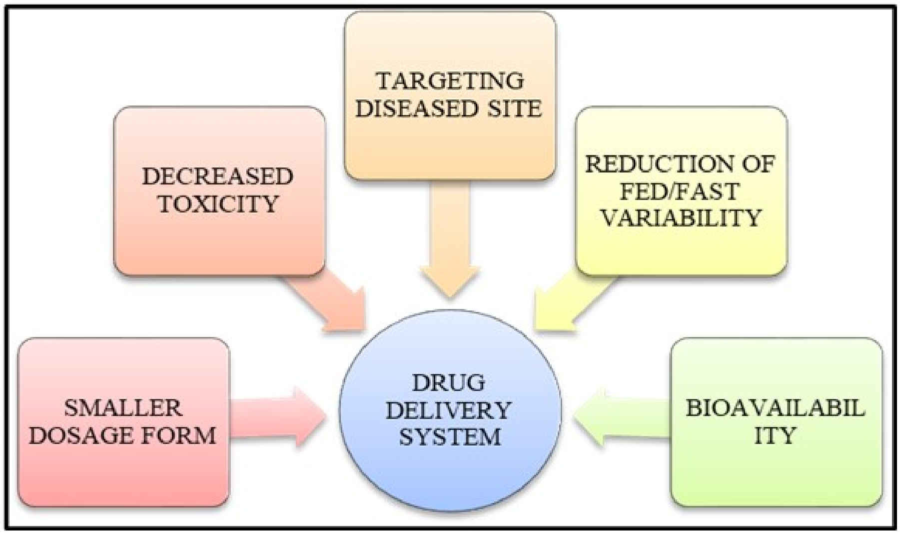

Figure 9: Advantage of Nano-Scale Drug Delivery System

2. **Drug Discovery:** The utilization of high throughput arrays & highly sensitive labeling and detection technologies has been employed to enhance the efficiency and precision of identifying genes and genetic materials that are essential for drug discovery &development.

3. **Diagnostic/Imaging Application:** Super paramagnetic iron oxide nanoparticles for MRI scanning, magnetic iron oxide nanoparticles are used for detecting Alzheimer's plaque. Colloidal gold particle, owing to their inherent stability, are employed for expeditious pregnancy and HIV testing.

4. **Nanotechnology in treating and diagnosing infectious disease:** Nanobots function similar to WBCs in the body that eliminates the infection within a minute in patient, microbivore nanorobots designed such that antibodies attach to the bacteria the nanorobot is seeking. Modulation of Immune Response by Nanoparticles (NPs) for Efficient Vaccination, The activation of the cell-mediated immune response is a crucial objective in enhancing the effectiveness of therapeutic agents. Nanoparticles (NPs) can serve as a carrier to transport encapsulated vaccines (antigenic proteins) to specific locations and gradually release them over an extended period to enhance the immune response. Nanoparticles (NPs) that have undergone suitable surface modifications possess the capability to interact with biomolecules, including proteins and DNA. The distinctive physical and chemical characteristics of NPs enable precise, swift, sensitive, and cost-effective diagnostics [28-30].

5. **Thermography:** Nanomaterial's like Nanosized iron oxides, gold coated silica nanoparticles and hafnium oxide nanoparticles are used to generate the heat to destroy cancer cells.

6. **Labeling of Biological Molecules:** Quantum dots, such as nano zinc and cadmium, are semiconductor nanoparticles that have been utilized for the labeling of biological molecules. These nano crystals have found applications in high throughput drug screening, targeted therapeutics and medical diagnostics.

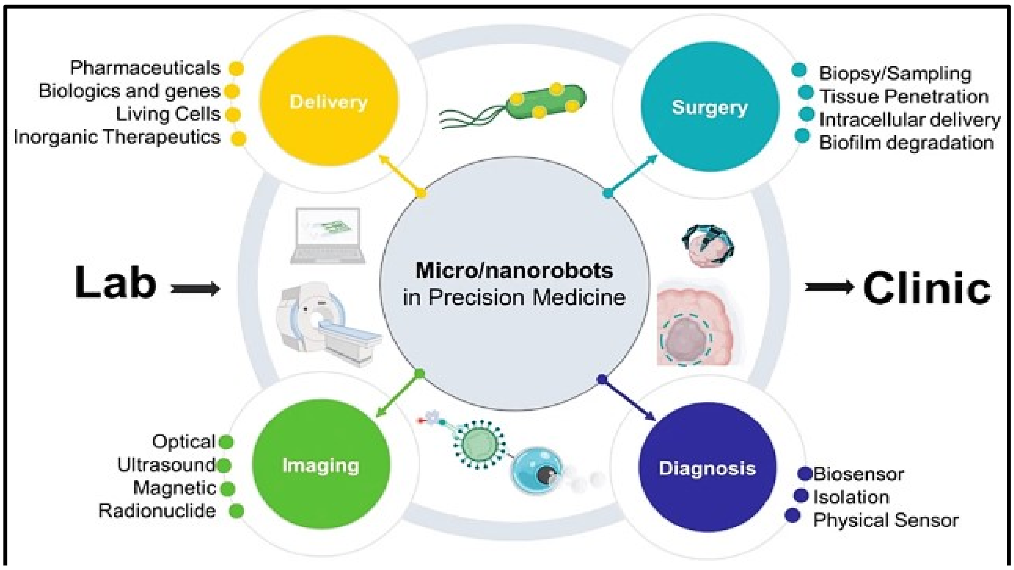

Figure 10: Nanorobotics in Precision Medicine

(**Source:** Aggarwal M, Kumar S (September 20, 2022) The Use of Nanorobotics in the Treatment Therapy of Cancer and Its Future Aspects: A Review. Cureus 14(9): e29366. doi:10.7759/cureus.29366) [40]

Table 1: Advantages & Disadvantages of Nanotechnology

ADVANTAGES	DISADVANTAGES
Improved Drug: Enhance the stability, bioavailability, and solubility of drugs. This can result in the administration of lower dosages, thereby mitigating the potential for toxicity and adverse effects. [31]	**Nanotoxicity**: certain nanoparticles can accumulate within the body and cause harm to organs and tissues[33]
Targeted therapy: nanoparticles engineered to target specific cells or tissues in the body, particularly in cancer therapy. Thus reducing the risk of damage to healthy cells and tissues [32].	**Ethical issue**: Ethical concerns also surround the use of Nanomedicine, particularly in genetic engineering and enhancement [34]
Precision Medicine: enables targeted drug delivery. Thus reducing the risk of side effects and maximizes the therapeutic effect of drug.	**Limited Knowledge**: We don't know enough about how nanoparticles affect the human body se need to study more to for better understanding of nanomedicine.[35]
Regenerative Medicine: deliver growth factors and other regenerative agents to damaged tissues, promoting tissue repair and regeneration.	**Regulatory Challenges**: The use of nanomedicine in humans must go through strict rigorous regulatory approval, which can hinder the advancement and execution of novel therapies [36]
Early Diagnosis: facilitated by nanotechnology based imaging techniques, such MRI, CT scans,	**Cost**: The development and production of nanoparticles is a costly endeavor

VII. CONCLUSION

Nanomedicine possesses the capacity to bring about a significant transformation in the field of medicine and enhance the well-being of patient. Nanomedicine has emerged as a highly promising field with significant potential for revolutionizing healthcare. By harnessing the power of nanotechnology, this discipline offers innovative solutions for the diagnosis, treatment, and prevention of diseases at the molecular level. The remarkable advancements achieved in nanomedicine have paved the way for the development of personalized medicine, targeted drug delivery, and enhanced imaging techniques. Furthermore, the integration of nano material's and nanodevices holds great promise in enhancing the effectiveness and safety of therapeutic interventions. However, it is essential to acknowledge the challenges and ethical considerations associated with nanomedicine, including potential toxicity and regulatory issues. In order to fully realize Nanomedicine ongoing research and further development are needed. Hence, it is imperative to prioritize further research, collaboration, and the implementation of stringent regulations to promote the widespread adoption of nanomedicine. The advancement of our understanding and application of this state-of-the-art discipline heavily relies on conducting additional research in the field of nanomedicine. It is of utmost importance to carry out comprehensive investigations to elucidate the mechanisms of action, safety, and efficacy of nanomedicine interventions. Moreover, rigorous studies are necessary to optimize the synthesis and characterization of nanomaterial's, ensuring their reproducibility and scalability. Additionally, the development of standardized protocols and regulatory frameworks is crucial to facilitate the translation of nanomedicine from the laboratory to clinical practice. Ultimately, these endeavors will not only benefit patients but also contribute to the advancement of healthcare on a global scale.

REFERENCES

[1] Swain, S.; Sahu, P.K.; Beg, S.; ManoharBabu, S. Nanoparticles for Cancer Targeting: Current and Future Directions. Curr. Drug Deliv. 2016, 13, 1290–1302. [CrossRef]
[2] Zhang, W.; Lu, Y.; Zang, Y.; Han, J.; Xiong, Q.; Xiong, J. Photodynamic Therapy and Multi-Modality Imaging of Up-Conversion Nanomaterial Doped with AuNPs. Int. J. Mol. Sci. 2022, 23, 1227. [CrossRef]
[3] Bleeker, E. A., de Jong, W. H., Geertsma, R. E., Groenewold, M., Heugens, E. H., Koers-Jacquemijns, M., et al. [2013]. Considerations on the EU definition of a nanomaterial: science to support policy making. Regul. Toxicol. Pharmacol. 65, 119–125. doi: 10.1016/j.yrtph.2012.11.007
[4] Ossa, D. Quality Aspects of Nano-Based Medicines SME Workshop: Focuson Quality for Medicines Containing Chemical Entities London. [2014] Available onlineat: http://www.ema.europa.eu/docs/en_GB/document_library/Presentation/2014/04/WC500165444.pdf
[5] Jarvie, H.; Stephen, K.; Dobson, P. Nanoparticle. Encyclopedia Britannica. 2019. Available online: https://www.britannica.com/ science/nanoparticle [accessed on 10 March 2023].
[6] Chapman, S.; Dobrovolskaia, M.; Farahani, K.; Goodwin, A.; Joshi, A.; Lee, H.; Meade, T.; Pomper, M.; Ptak, K.; Rao, J.; et al Nanoparticles for cancer imaging: The good, the bad, and the promise. Nano Today 2013, 8, 454–460. [CrossRef]
[7] Baetke, S.C.; Lammers, T.; Kiessling, F. Applications of nanoparticles for diagnosis and therapy of cancer. Br. J. Radiol. 2015, 88, 20150207. [CrossRef]
[8] K. Blecher, A. Nasir, and A. Friedman, Virulence 2, 395 [2011]
[9] Feynman, R.P. There's plenty of room at the bottom. Eng. Sci. 1960, 23, 22–36.
[10] Taniguchi, N.; Arakawa, C.; Kobayashi, T. On the basic concept of nano-technology. In Proceedings of the International Conference on Production Engineering, Tokyo, Japan, 26–29 August 1974.
[11] Viseu, Ana. "nanomedicine". Encyclopedia Britannica, 23Sep.2020,https://www.britannica.com/science/nanomedicine. Accessed 22 August 2023
[12] S. Khan, M. K. Hossain, In Nanoparticle-Based Polymer Composites. Woodhead, London; 2022, 15.
[13] H. S Y. Khan, S. Z. Ali Shah, M. N. Khan, A. A.

Shah, Catalysts 2022, 12, 1386. https://doi.org/10.3390/catal12111386
[14] X. F. Zhang, Z. G. Liu, W. Shen, S. Gurunathan, Int. J. Mol. Sci. 2016, 17, 1534. https://doi.org/10.3390/ijms17091534
[15] Dendrimers. Available online: https://www.cd-bioparticles.net/biodegradable-polymers/dendrimers?page=2 [accessed on 1 January 2023].
[16] Zhang, M.; June, S.M.; Long, T.E. Principles of Step-Growth Polymerization [Polycondensation and Polyaddition]. In Polymer Science: A Comprehensive Reference, 10 Volume Set; Elsevier: Amsterdam, The Netherlands, 2012; Volume 5, pp. 7–47.
[17] Ren, L.; Wang, L.; Rehberg, M.; Stoeger, T.; Zhang, J.; Chen, S. Applications and Immunological Effects of Quantum Dots on Respiratory System. Front. Immunol. 2022, 12, 5665. [CrossRef] [PubMed]
[18] Xu, Y.-M.; Tan, H.W.; Zheng, W.; Liang, Z.-L.; Yu, F.-Y.; Wu, D.-D.; Yao, Y.; Zhong, Q.-H.; Yan, R.; Lau, A.T.Y. Cadmium telluride quantum dot-exposed human bronchial epithelial cells: A further study of the cellular response by proteomics. Toxicol. Res. 2019, 8, 994–1001. [CrossRef] [PubMed]
[19] Alrushaid N, Khan FA, Al-Suhaimi EA, Elaissari A. Nanotechnology in Cancer Diagnosis and Treatment. *Pharmaceutics*. 2023; 15[3]:1025. https://doi.org/10.3390/pharmaceutics15031025
[20] Javanbakht, S.; Namazi, H. Doxorubicin loaded carboxymethyl cellulose/graphene quantum dot nanocomposite hydrogel films as a potential anticancer drug delivery system. Mater. Sci. Eng. C 2018, 87, 50–59. [CrossRef]
[21] Amreddy, N.; Ahmed, R.A.; Munshi, A.; Ramesh, R. Tumor-Targeted Dendrimer Nanoparticles for Combinatorial Delivery of siRNA and Chemotherapy for Cancer Treatment. Drug Deliv. Syst. 2019, 2059, 167–189. [CrossRef]
[22] https://roboticsbiz.com/nanorobots-key-components-and-substructures/
[23] Cavalcanti A, Shirinzadeh B, Kretly L C. Medical nanorobotics for diabetes control. Nanomedicine: Nanotechnology, Biology and Medicine, 4[2], 2008, 127-138.
[24] Leja, M.; Line, A. Early detection of gastric cancer beyond endoscopy—New methods. Best Pract. Res. Clin. Gastroenterol. 2021, 50–51, 101731. [CrossRef]
[25] Qiao, K., Xu, L., Tang, J. et al. The advances in nanomedicine for bone and cartilage repair. J Nanobiotechnol 20, 141 [2022]. https://doi.org/10.1186/s12951-022-01342-8 13].
[26] Lei Y, Xu Z, Ke Q, Yin W, Chen Y, Zhang C, et al. Strontium hydroxyapatite/chitosan nanohybrid scaffolds with enhanced osteoinductivity for bone tissue engineering. Mater SciEng C Mater Biol Appl. 2017;72:134–42.
[27] Surender Esther M, Comby S, Cavanagh BL, Brennan O, Lee TC, Gunnlaugsson T. Two-photon luminescent bone imaging using europium nanoagents. Chem. 2016;1[3]:438–55.
[28] Qasim M, Lim DJ, Park H, Na D. Nanotechnology for diagnosis and treatment of infectious diseases. J NanosciNanotechnol. 2014 Oct;14[10]:7374-87. doi: 10.1166/jnn.2014.9578. PMID: 25942798.
[29] N. L. Rosi and C. A. Mirkin, Chem. Rev. 105, 1547 [2005].
[30] F. E. Andre, R. Booy, H. L. Bock, J. Clemens, S. K. Datta, T. J. John, B. W. Lee, S. Lolekha, H. Peltola, T. A. Ruff, M. Santosham, and H. J. Schmitt, Bull. World Health Organ. 86, 140 [2008].
[31] Hemphill A, Müller N, Müller J. Comparative pathobiology of the intestinal protozoan parasites Giardia lamblia, Entamoebahistolytica, and Cryptosporidium parvum. Pathogens. 2019;8[3]:116.
[32] Khan W, Rahman H, Rafiq N, Kabir M, Ahmed MS, Escalante PD. Risk factors associated with intestinal pathogenic parasites in schoolchildren. Saudi J Biol Sci. 2022;29[4]:2782-2786.
[33] Opara KN, Udoidung NI, Opara DC, Okon OE, Edosomwan EU, Udoh AJ, et al. The impact of intestinal parasitic infections on the nutritional status of rural and urban school-aged children in Nigeria. Int J MCH AIDS. 2012;1[1]:73.
[34] Pfuhler S, Elespuru R, Aardema MJ, Doak SH, Maria Donner E, et al. Genotoxicity of nanomaterials: refining strategies and tests for hazard identification. Environ Mol Mutagen. 2013; 54[4]:229-239.
[35] Levecke B, Montresor A, Albonico M, Ame SM, Behnke JM, Bethony JM, et al. Assessment of anthelmintic efficacy of mebendazole in school children in six countries where soil-transmitted helminths are endemic. PLoSNegl Trop Dis. 2014; 8[10]:e3204.
[36] Elespuru R, Pfuhler S, Aardema MJ, Chen T, Doak SH, et al. Genotoxicity Assessment of Nanomaterials: Recommendations on Best Practices, Assays, and Methods. Toxicol Sci. 2018; 164[2]:391-416.
[37] Nsairat H, Khater D, Sayed U, Odeh F, Al Bawab A, Alshaer W. Liposomes: structure, composition, types, and clinical applications. Heliyon. 2022 May 13;8(5):e09394
[38] T. Maruyamam,Carbon nanotubes, Handb.Carbon-Based Nanomater.Micro Nano Technol.(2021)
[39] L. Huang, F. Chen, Y. Lai, Z. Xu, H. Yu, *ChemBioChem* **2021**, *22*, 3369.
[40] Aggarwal M, Kumar S (September 20, 2022) The Use of Nanorobotics in the Treatment Therapy of Cancer and Its Future Aspects: A Review. Cureus 14(9): e29366. doi:10.7759/cureus.29366.