



Nano-Medicine: Creating Revolution In Future Healthcare

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Abstract:

Nanomedicine, or the use of nanotechnology in healthcare, is a cutting-edge field of study that uses extraordinary precision to alter biological systems at the nanoscale. This quickly developing field has significant effects on medication delivery, disease treatment, and diagnostics. Especially in cancer treatment, nanoparticles can be designed to deliver medications to specific locations within the body, reducing adverse effects and increasing therapeutic efficacy. Furthermore, nanomaterials are becoming more and more significant in the field of diagnostics, as Nano sensors are able to identify diseases in their early stages and provide prompt treatment. Nanotechnology is used in regenerative medicine to create scaffolds that assist tissue growth, providing novel approaches to organ regeneration and tissue repair. Additionally, antibacterial qualities of nanoparticles like gold and silver provide novel approaches to infection prevention and treatment, particularly in light of the growing resistance to antibiotics. Nanomedicine still has a long way to go before realizing these exciting uses. One major obstacle is the safety and long-term impact of nanomaterials on the body. There are ethical issues as well, especially in relation to the possible development of human potential and fair access to cutting edge medical care. However, nanomedicine has a bright future ahead of it, with continued research set to increase its uses and enhance patient outcomes. Nanomedicine is anticipated to be crucial to the advancement of personalized and precision medicine as nanotechnology continues to be integrated with robots and artificial intelligence. The potential of nanomedicine to transform healthcare through earlier diagnosis, more focused therapies, and creative solutions for challenging medical problems is highlighted in this abstract. Ultimately, this could lead to an improvement in global quality of life.

Keywords: Nanomedicine, Nanoparticles, Drug delivery systems, Targeted therapy, Biomaterials, Cancer treatment, Imaging techniques, Biocompatibility, Nanotechnology, Therapeutic agents.

Introduction:

The word nanotechnology is made-up of two words. 'Nano' which is a Greek word, which means 'diminutive' and 'technology' means 'skills' or 'craft' such as devices which we used in our daily life. The nanomaterials of nanotechnology are observed, measured or manufactured at the nanometer scale which is referred to the structure whose length applicable to the size of between 1-100nm. [1] In nanotechnology, nanoparticles used for various purpose such as, cancer treatment, formation of nucleic acid etc. [2] In nanotechnology, Gold is extremely exercised nanoparticle to induced the molecules into cells because of its ability to work as a detector and Quantum dots are crystalline nanoparticles in which the QDs which have small crystals illuminates blue and which have large crystals illuminates red. [3] Nanoparticle of nanotechnology are applied in the creation of new drugs which is known as nanomedicine. It is used for the treatment of disease by acting on the particular affected area which reduces the risk factor. [4] Nanomaterials are applied in the medicine for monitoring the physiology of cardiovascular system to the output of creams which prevent from UV radiation by using titanium nanoparticle. In animals' nanomedicine used for releasing of estrogen hormone for a specific time and nanomedicine which are made of silver nanoparticle used as antibacterial and anti-microbial agent [5] Nanoparticle of nanomedicine penetrate into the cell by the embody mechanism, deposition at the targeted site of the body and excreted out from the body by renal and hepatobiliary duct. The advantage of nanomedicine having the ability to enter in body by the cell penetration, inhalation and gastro intestinal tract and the disadvantages of nanomedicine is toxic effects in cytoplasm of cell which promote the limited use of nanomedicine. [6]

1. Nanomedicine for animals:

Significant progress in reproductive health and reproduction especially in animal reproduction, is being driven by nanotechnology. These advancements use nanoscale technologies to improve reproductive methods; for example, gamete cell analysis may now be done at a previously unheard-of degree of detail thanks to the use of scanning and atomic force microscopy. Furthermore, nano-biosensors are being created to monitor physiological changes and detect reproductive statuses with greater accuracy. By creating metal nanoparticles, nanotechnology is also being investigated for fertility control. This could lead to the development of new chemical strategies for reproductive control. Additionally, safer and more effective preservation and storage procedures are guaranteed by the development of nanodevices, which will enhance the cryopreservation of gametes and embryos. [7] For pig and dairy farmers, managing the breeding process may be quite expensive and time-consuming. One experimental approach being tested uses subcutaneously placed nanotubes to detect changes in blood estradiol levels, allowing real-time estrus monitoring. These nanotubes use near-infrared fluorescence to signal the start of estrus and bind to antibodies against estrogen.

The signals from the sensor are intended to be combined with a central breeding monitoring and control system to enable automated judgment calls and breeding process interventions. [8] Devices utilizing nanotechnology, such as bioanalytic nano-sensors, nanoparticles, and microfluidics, have the ability to solve difficult problems pertaining to the growth, health, and reproduction of animals as well as the prevention and treatment of disease. These cutting-edge instruments provide accurate nanoscale biological process monitoring and control, opening up new avenues for enhancing animal welfare, increasing reproductive success, and creating more potent disease preventive and management plans for livestock. [9] Modern techniques that can greatly improve both the development of in vitro embryos and traditional in vitro fertilization (IVF) procedures are microfluidic and nanofluidic technology. By precisely controlling the cellular environment and maximizing circumstances for fertilization and embryo growth, these cutting-edge techniques can raise the success rates and efficiency of in vitro fertilization (IVF) and associated reproductive technologies. [10,11] According to recent research, centrifugation is not necessary while isolating motile sperm thanks to the efficacy of microfluidics. In addition to increasing the quality of sperm utilized in fertilization processes and possibly raising the success rates of assisted reproductive technologies, this method provides a more effective and minimally disruptive way to sperm selection. [12] The development of nanoscale medications, regulated delivery methods, and contaminant detection made possible by nanotechnology is improving the domains of veterinary medicine, animal husbandry, and animal welfare. Smart drug delivery systems are expected to play a major role in the management of disease. One noteworthy application that is currently being developed is the use of nanoparticles to target and deliver medications to particular cell types. By designing the particles to specifically target diseased cells, targeted treatment can be provided along with enhanced therapeutic outcomes. [13,14]

2. Nanomedicine for targeted drug delivery:

The term "drug delivery" (DD) refers to the procedures, formulations, technologies, and methods utilized to move pharmaceuticals through the body in order to produce the intended therapeutic outcome. New developments centre on smart drug delivery systems (DDSs), which are intended to deliver drugs with improved safety and effectiveness at the right time, dose, and location. By addressing actual medication demands, novel DDSs (NDDSs) seek to increase treatment effectiveness through targeted, controlled, and sustained delivery. Targeted delivery systems (TDDSs) are the fourth generation in the field's evolution, which has seen five generations of development. These technologies, like bilayer tablets, combine several scientific fields like molecular biology, pharmacology, and polymer science to deliver medications to precise areas. TDDSs provide precise site-specific medication delivery while reducing side effects to maximize treatment efficacy. [15] There are many different kinds of drug carriers, including as cells, polymers, colloidal, and monoclonal antibodies (Abs). The drug's composition, the intended location, and the particular stage of the illness all influence the carrier selection. To improve medication delivery precision, carriers can be paired with targeting moieties such polysaccharides, proteins, lipoproteins, hormones, and charged compounds. [16] Pharmaceutical drug delivery systems (DDSs) rely heavily on polymers because of their special qualities that other materials might not have. Polymer technology advancements have made it possible to create a variety of innovative DDSs, which improve efficiency, effectiveness, and safety in medical treatment. Polymers are essential for sophisticated DDS applications because they can be utilized as excipients and delivery aids, allowing for controlled and targeted drug release. [17]

3. Nanomedicine for cancer treatment:

There are many benefits to developing therapeutics at the nanoscale, especially when it comes to resolving problems with anticancer medication solubility and stability. Chemical stability and bioavailability of poorly soluble medications can both be improved by nanoparticles. For instance, the low solubility and stability of wortmannin, a radiosensitizer and P13K inhibitor, presented development issues. But employing lipid-based nanocarriers enhanced both its stability and solubility, raising it from 4 mg/L to 20 g/L. [18] Using nanocarriers to carry anticancer drugs has various advantages. They improve the pharmacokinetic profile of the substances by shielding medications from elimination or breakdown by digesting proteases or RNases. Medication encapsulation in nanocarriers can stop a drug's breakdown. Furthermore, because of the physicochemical characteristics of anticancer medications, nanotechnology can enhance their targeting and distribution, facilitating more effective drug delivery to tumour tissues. [19] By facilitating better penetration and targeting, nanomedicine can improve drug delivery by enabling chemicals to be targeted particularly at cancer cells or stromal cells. It is possible to target this using both active and passive methods. Furthermore, it is possible to design nanocarriers so that they release their cargo in reaction to particular triggers, like pH variations. For example, doxorubicin can be delivered more efficiently by using pH-sensitive nanoparticles since they increase cellular absorption and release the medication inside the cell. [20] Treatments are customized via personalized medicine to each patient's particular genetic and physiological characteristics. By considering each patient's unique reactions to therapy, Nano based pharmaceuticals have demonstrated encouraging outcomes in this strategy, optimizing therapeutic effectiveness and decreasing toxicity. [21]

4. Nanomedicine for regenerative medicine:

Drug delivery systems in regenerative medicine have advanced significantly with the development of peptide and protein microencapsulation techniques. In the 1990s, PLGA microspheres were used to encapsulate peptides such as V3 BRU and pBC 264, enhancing their stability and controlled release for applications in HIV vaccination and Parkinson's disease treatment. Additionally, these systems were optimized to create a twice-monthly injectable delivery for vapreotide, used in treating acromegaly and neuroendocrine tumours. More recently, protein encapsulation has focused on glial cell line-derived neurotrophic factor (GDNF) for Parkinson's disease, using methods like double emulsion solvent evaporation and TROMS to improve protein stability and delivery to the brain, addressing challenges related to bioactivity and bioavailability. [22] Novel biomimetic nanomaterials and functionalized traditional materials have advanced regenerative medicine. Nanofibers offer a larger surface area than conventional scaffolds, providing more adhesion sites for cell receptors. Additionally, incorporating nanoparticles into traditional biomaterials can improve the mechanical properties and biocompatibility of orthopaedic implants, enhancing osseointegration at the bone-implant interface. [23] 5. Nanomedicine in tissue engineering: Bone is a mineralized connective tissue composed of osteocytes, osteoblasts, and osteoclasts. Its extracellular matrix (EC M) is biphasic, consisting of roughly 30% organic matter and 70% minerals. The skeleton and collagen fibers, primarily COL1, develop first, and then growth factors control mineral deposition, which gives bone its strength and hardness. Bone is divided into two types: cancellous bone, which has a high porosity of 50–90% and many blood vessels, and cortical bone, which has few blood vessels and a low porosity of 10%. This blood supply facilitates bone regeneration by remodelling continuously in response to changes in the external environment. External intervention is necessary for serious bone injury that exceeds the bone's inherent ability to mend itself. [24,25,26,27] The ability of traditional bone repair techniques to encourage quick and efficient bone

regeneration is limited. While allografts run the danger of immunological rejection and disease transmission, autografts are limited by donor scarcity and donor site morbidity. The healing process is further complicated by the fact that both metallic and non-metallic implants used in bone repair are vulnerable to issues including bacterial adhesion and corrosion. [28,29]

6. Nanomedicine for antimicrobial treatment:

Bacterial infections are a global health threat, and antibiotics, once the standard treatment, are now less effective due to the rise of antibiotic-resistant strains. These include multidrug-resistant bacteria, which complicate the treatment of various infections. Antimicrobial peptides (AMPs), natural bioactive peptides produced by organisms, offer an alternative. They are part of the innate immune system and kill bacteria by disrupting their membranes. AMPs have a low potential for resistance development, making them promising for infection treatment. However, issues with stability, safety, and bioavailability hinder their effectiveness. Nanomedicine offers a potential solution by using nanocarriers to enhance AMP delivery, improving stability, targeting, and controlled release at infected sites. Nanomaterials are already used in antibacterial therapies, and future advancements in AMP nanomedicine could further optimize treatment outcomes. [30] One of the most pressing issues of our time is the spread of bacterial resistance to alternative antibiotics. The two main causes of this resistance are: (1) the bacterial genetic resistance to antibiotics, as shown in multiple drug-resistant *Staphylococcus aureus* (MRSA); and (2) the development of firmly adhering, antibiotic-resistant biofilms. Therefore, it is crucial to create innovative treatments that could solve these issues. Because of their unique method of action and powerful antibacterial capability, nanoparticles are a superior alternative to traditional antibiotic therapy. [31,32] Because biofilm formation and genetic tolerance in bacteria (like MRSA) both increase resistance to antibiotics, bacterial resistance to these drugs is becoming a bigger problem. Novel medicines are required to address this, and because of their special antibacterial qualities, nanoparticles offer a possible substitute for traditional antibiotics. Specifically, metal nanoparticles are less detrimental to mammalian cells but poisonous to bacteria. Although the precise process underlying their selectivity remains unclear, nanoparticles are thought to adhere to bacterial cell walls and interfere with their permeability. In addition, they release harmful reactive oxygen species (ROS), which enhances their antimicrobial properties. Based on their composition, nanoparticles utilized in antibacterial therapeutics can be broadly classified into two groups. [33,34]

7. Nanomedicine using biomimicry:

Recent research shows that PEG-modified Nano-medications nevertheless experience rapid liver clearance with repeated usage, a condition known as accelerated blood clearance (ABC), despite the fact that PEG has been utilized to change nanoparticle surfaces to limit clearance by the reticuloendothelial system (RES). Furthermore, PEG's therapeutic applicability may be hampered by the hypersensitive reaction known as complement activation-related pseudo allergy (CARPA). Thus, efforts are being directed toward creating biomimetic nano-systems that are more suited for in vivo medication delivery; the most noteworthy developments in this regard are cell membrane-coated nanoparticles and EV-based nanocarriers. [35,36]

8. Nanomedicine for imaging:

Molecular imaging has recently gained attention in medical imaging research, focusing on studying biological processes at the cellular and molecular levels in vivo to enable early and targeted disease detection. Traditional isotope labelling techniques, like PET, require radioactive contrast agents but offer unsatisfactory image quality. With advancements in nanotechnology, nanoparticle-based MRI contrast agents (e.g., superparamagnetic iron oxide nanoproboscopes) have emerged, allowing for high-resolution, low-radiation imaging, particularly for skeletal diseases. MRI offers superior spatial resolution and the ability to capture anatomical and physiological data simultaneously. For instance, europium-emitting, gold nanoparticle-based MRI contrast agents have been developed to target bone microdamage, enabling early detection of fracture-prone areas while reducing the toxicity of the probes. [37,38,39]

9. Nanomedicine for diagnosing:

Nano-diagnostics involve using nanomaterials for labelling, tracing, detecting, and enhancing signals in living organisms to enable rapid diagnosis and point-of-care testing (POCT) for early diseases. Key research areas include bio-barcode assays, nanofluidic arrays (biochips), nanoparticles, quantum dots (QDs), and Nano biosensors. These technologies facilitate ultra-sensitive detection, high-throughput analysis, non-invasive cell tracking, fluorescent labelling, and nanoprobe development. For instance, a lateral flow immunoassay (LFIA) method using fluorescent cadmium telluride QDs was developed to detect inflammatory biomarkers like C-reactive protein and IL-6, showing high accuracy and sensitivity, comparable to ELISA. [40,41,42,43,44,45] Jin et al. developed a nitric oxide (NO) Nano sensor for non-invasive, real-time monitoring of osteoarthritis (OA). This sensor, created by encapsulating NO sensing molecules in biodegradable poly (lactic-co-glycolic acid) nanoparticles, demonstrated a positive correlation between fluorescence intensity and NO concentration in chondrocytes in vitro. It was also effective in quantifying NO levels in joint fluid in a rat OA model. Additionally, a gold nanoparticle-based biochip was developed to detect osteoprotegerin, a protein linked to osteoporosis, aiding in the assessment of bone remodelling and providing accurate diagnosis of bone damage. [46,47,] New technologies like atomic force microscopy (AFM) are being used to analyse the micromechanical properties of bone tissue. Hengsberger et al. demonstrated the advantages of AFM combined with nanoindentation over traditional optical microscopy. By testing four bone structural units (BSUs) from dehydrated bone tissue with 24 indents at a maximum force of 5 mN, they found that AFM could accurately capture surface features and measure intrinsic mechanical properties of each BSU, providing greater precision than conventional optical methods. [48]

10. Future perspective of Nanomedicine:

Although standard medications can be made more effective by using nanotechnology, many nanotherapeutics still cause harm to healthy tissues since they do not target particular lesions. The development of targeted medications that concentrate in sick tissues rather than healthy ones is a key objective for next-generation nanotherapeutics. Smart drug delivery systems that are responsive to stimuli and feature active targeting have recently been created, providing a potential approach to eradicate abnormal tissues while sparing healthy ones. These systems pose a difficulty as well as an opportunity for nanomedicine's future. [49]

11. Challenges in Nanomedicine:

Although there are an increasing number of nanotherapeutics in the medical research pipeline, the clinical translation efficiency is not up to par. The poor effectiveness of clinical translation of nanotherapeutics suggests that issues still need to be resolved. While each nanotherapeutic has unique difficulties throughout the clinical translation stage, all nanotherapeutics have common obstacles related to safety, biology (such as biodistribution), cost and scale-up, and regulation. Nanotherapeutics come into contact with a variety of biological settings after they reach the body, including the blood, cytoplasm, extracellular matrix, and cellular organelles. [50,51] Because nanotherapeutic safety issues are complicated, thorough evaluations are necessary before clinical usage. Standardized techniques for assessing the safety of nanodrugs are lacking, nevertheless. Nanotherapeutics' distinct physicochemical characteristics— such as size, shape, surface area, and aggregation—can change biodistribution and interactions with cells and biomolecules, making traditional drug safety screening techniques insufficient. [52,53] Combining new nanotherapeutics and nanocarriers with well-known medications, such as doxorubicin and paclitaxel, can lead to complicated toxicity problems. The toxicity of nanocarriers can be greatly influenced by the coatings and ligands that are utilized. To improve the effectiveness of clinical translation for novel nanotherapeutics, it is important to comprehend the physicochemical properties of nanoparticles, the features of nanocarriers, and the toxicity of these medications. New safety evaluations may also be required if the synthesis pathway, reagents, manufacturing processes, or routes of administration change in a way that affects toxicity. [54]

Conclusion:

Nanomedicine represents a paradigm shift in healthcare, offering the potential for earlier diagnoses, more effective treatments, and even the regeneration of damaged tissues. While challenges remain, the continued advancement of nanotechnology in medicine holds the promise of transforming the way we approach disease and improving the quality of life for millions of people worldwide. As research in this field continues to progress, nanomedicine may one day become a cornerstone of modern healthcare.

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