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Nanotechnology at the Molecular Frontier: Transformative Applications, Therapeutic Innovations, and Future Directions in Molecular Biology and Biomedical Engineering

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ABSTRACT

Nanotechnology has come out as a revolutionary and interdisciplinary platform, which allows tight control of both biological systems at the molecular and atomic levels with significant influence on molecular biology and biomedical engineering. Through manipulation of unusual nanoscale physicochemical characteristics: improved surface area, quantum effects, controllable functionality, nanomaterials have enabled important regenerative medical, imaging, diagnostic, and therapeutic breakthroughs. This review critically and thoroughly presents recent advancements in nanotechnology enabled applications in the fields of molecular biology and biomedical engineering. The major improvements in nanoparticle-mediated gene delivery, CRISPR/Cas genome editing, molecular diagnostics, biosensing, and bioimaging are highlighted, and how nanocarriers and DNA nanostructures can be used to circumvent the drawbacks of traditional biological instruments. The problem of biomedical engineering is discussed, and breakthroughs in controlled and targeted drug delivery systems, nanostructured tissue engineering scaffolding, theranostic systems, and biosensors based on nanotechnology are explored with respect to their contribution to precision and personalized medicine. The review also discusses therapeutic uses of nanotechnology in cancer, cardiovascular, neurodegenerative and infectious disease along with case studies in the recent findings in the clinical and

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translational uses of smart, plant-based and DNA-based nanomaterials. The most critical issues such as nanotoxicity, biocompatibility, environmental effects, regulatory concerns, and massive production are analyzed in a systematic manner and offer the balanced approach to understanding the prevailing barriers. Lastly, future directions where nanotechnology will be combined with artificial intelligence, tailored medicine and sustainable nanomaterial design are also mentioned, as these are emerging opportunities that will drive clinical translation faster. Overall, this review highlights the critical role that nanotechnology plays in the development and evolution of molecular and biomedical sciences and its future use in the definition of next-generation diagnostic and therapeutic measures in healthcare.

Keywords;
Nanotechnology; Molecular Biology; Biomedical Engineering; Nanomedicine; Gene Delivery

Introduction

Nanotechnology is a disruptive technology that uses atomic and molecular matter at a smaller scale, generally less than 100 nanometers of its length, and it allows the tailoring of systems and new functionalities that can be more precise and functional (Patel et al., 2024). It is now a key technology in the field of molecular biology and biomedical engineering, and it has led to breakthroughs in all areas of diagnostics, therapeutics, drug delivery, imaging, and tissue engineering. Nanotechnology in molecular biology enables the manipulation and the study of important biomolecules, including proteins and DNA, in an unparalleled precision. An example of such is DNA nanotechnology, which uses very specific nanostructures to biosense and targeted therapeutics, which takes advantage of the high programmability and biocompatibility of DNA to treat things such as cancer (Shen et al., 2021). In the biomedical engineering field, nanotechnology facilitates the creation of nanomaterials and nanoparticles that have special physicochemical characteristics. The functional types of nanoparticles that impact diagnostics, imaging agents, and therapeutics include metal types of nanoparticles, quantum dots, and carbon-based nanostructures (Ray and Bandyopadhyay, 2021; Canaparo et al., 2020). An example of such applications is the field of nano-oncology where nanocarriers like dendrimers, liposomes, and polymeric nanoparticles are used to intensify the targeted therapy of cancer to achieve better results and fewer side effects. The quantum dots provide images of the tumors and real-time tracking of therapy (Tiwari et al., 2023). Moreover, nanotechnology is complementary to tissue engineering since it gives nanoscale scaffolds on which cells grow and regenerate into tissues, which are required to repair tissues that are damaged (Matic et al., 2023). Nanotechnology and bioorthogonal chemistry are combined to make biomedical applications more effective and efficient in the production of improved bioimaging, biosensing, and therapeutic nanoplatforms (Idiago-Lopez et al., 2021). The goals and coverage of the reviews in the field tend to cover the summing up of the current nanotechnology-enabled solutions in molecular biology and biomedical engineering, innovations related to nanomaterials and nanoparticles in the context of diagnostics and therapeutics, challenges, including nanotoxicity and regulatory concerns, and

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perspectives, including personalized medicine and nano-medicine platforms (Patel et al., 2024; Ray and Bandyopadhyay, 2021). Such an interdisciplinary convergence will transform the world of healthcare and will be able to find specific diagnostics, appropriate therapies, and regenerative solutions on a molecular scale.

Fundamental Principles of Nanotechnology

Nanotechnology is a transdisciplinary area of science concerned with the handling and the exploitation of materials in the nanometer scale, which is represented by 1-100nm, to harness their peculiarities of a physical, a chemical, and a biological nature (Shinde et al., 2022; Szczyglewska et al., 2023). The basic concepts of nanotechnology involve learning the behavior of materials at this size and quantum effects and higher surface to volume ratios play significant roles in changing the properties of materials in comparison to their bulk versions. The most basic units in nanotechnology are nanomaterials which have been classified into various fundamental groups depending on their structure and composition. The metallic nanoparticle, which is nanofabricated with the use of metals like gold and silver or platinum, has unique electrical, optical, and catalytic characteristics due to their small size and a large surface energy (Szczyglewska et al., 2023). Polymeric nanoparticles are produced out of organic polymers that have the following benefits: biodegradability, low toxicity, functional versatility, and therefore are the most effective when it comes to drug delivery and therapeutic usage (Quazi & Park, 2022). Carbon-based nanostructures (such as carbon nanotubes, graphene, and fullerenes) are notable due to their superior mechanical strength, electrical conductivity, as well as thermal stability and have found a wide range of applications in electronics, energy storage and composite materials (Xiao et al., 2021). Quantum dots are semiconductor nanocrystals, which have size dependent fluorescence caused by quantum confinement effects, and find critical uses in bioimaging and optoelectronics (Xiao et al., 2021). Production of nanoparticles is attained by diverse ways, and they can broadly be divided into top-down and bottom-up. Metallic nanoparticles are commonly synthesized by chemical reduction processes in which metal precursors are reduced to create nanoscale sized particles, which are often to be performed by the selection of the right reducing agent, solvent, and stabilizer to determine the size and morphology (Szczyglewska et al., 2023). Microreactor- and microfluidics-based synthesis is among the process intensification methods that have received interest in producing nanomaterials exhibiting a robust level of control in particle uniformity and scalability (Hakke et al., 2021). Green synthesis methods involve the use of biological systems, particularly bacteria, fungi, and algae, that bio-assemble nanoparticles sustainably and eco-friendly and reduce the number of toxic byproducts and energy usage (Huston et al., 2021; Wu et al., 2022). These biomimics techniques have potentials of being scalable to produce products with minimal ecological footprints. The analysis of nanoparticles is characterized by a complex of methods of analysis and identification of their size, shape, surface chemistry, crystallinity, and optical properties. Methods like transmission electron microscopy (TEM) and scanning electron microscopy (SEM) offer a high resolution of the morphology of nanoparticle. The force of dynamic light scattering (DLS) is the measurement method of hydrodynamic size distributions in suspensions. Optical characteristics that are

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essential in quantum dots and fluorescent nanoparticles can be explained using spectroscopic methods, such as UV- Vis absorption and photoluminescense spectroscopy (Xiao et al., 2021). Moreover, chemical composition and surface properties can also be studied with the help of X-ray diffraction (XRD), Fourier-Transform infrared spectroscopy (FTIR), as well as X-ray photoelectron spectroscopy (XPS) (Szczyglewska et al., 2023). The characterization approaches are essential in the alignment of the synthesis into nanoparticle tasks with nanoparticle performance across various applications.

Nanotechnology in Molecular Biology

The importance of nanotechnology in molecular biology is revolutionary in improving genetic engineering, gene delivery, diagnostics, imaging, biosensing and genome editing methods. Nanotechnology, in genetic engineering, enables manipulation and delivery of genetic materials and nanoparticles and nanoscale platforms in a precise and controlled fashion. Nanoparticles are also used as effective vectors to deliver genes while traditional viral vectors already have several shortcomings, including immunogenicity, packaging capacity and even genotoxicity. Gene delivery systems based on nanoparticles include liposomes, polymeric nanoparticles, gold nanoparticles, and others, which are used to deliver DNA, RNA or gene editing tools into target cells safely to enhance their therapeutic efficacy and specificity (Hejabi et al., 2022; Salman et al., 2022). Nanotechnology has been developed in genetic diagnostics to improve high sensitivity, specificity of molecular detection. CRISPR/Cas are nanotechnology-based systems that can make nucleic acid analysis ultrasensitive and programmable. These biosensors utilize fluorescent reporters or nanomaterial reporters controlled by cleavage collateral activity of Cas effectors (e.g., Cas12 and Cas13) on CRISPR template RNA via these two classes of biosensors and have already been used to enhance pathogen, genetic mutation, and biomarker diagnostics more quickly (Chen et al., 2022; Sahel et al., 2024). Nanotechnology has also made it possible to have miniature, portable and multiplexed detection devices, increasing accessibility in molecular diagnostics. In imaging and biosensing, nanoparticles have more contrast and targeting advantages. Fluorescent nanomaterials, quantum dots and gold nanoparticles are used in real time imaging at high resolution of biological systems. Functionalized nanoparticles are used to detect biomolecules of better sensitivity and selectivity in the form of biosensors, which can help in the diagnoses and monitoring of diseases (Chen et al., 2022). Nanotechnology is a part of the development of CRISPR/Cas genome editing through the resolution of delivery issues. The size and complexity of the CRISPR molecule lead to the development of nanoparticle-based non-viral delivery vectors that can effectively and safely deliver the components of CRISPR (DNA, RNA, or ribonucleoprotein complexes) Nanocarriers promote targeted delivery, uptake by cells, evasion of endosomes and regulated release, which are essential in successful genome editing in vivo (Salman et al., 2022; Hejabi et al., 2022). DNA nanostructures are also used with harnessed programmable carriers that enable them to precisely deliver parts of the CRISPR system, providing a new avenue of complex genome engineering applications (Piskunen et al., 2022). CRISPR delivery facilitated by nanotechnology is very helpful in the genetic engineering of plants. Nanoparticles alter species

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barriers and enhance the germline transformation and editing to enable enhancement of crops on resilience, productivity, and environmental renewability (Demirer et al., 2021; Vats et al., 2022). The technology is a potential beginning of solving the food security issues facing the world in the varied climatic conditions. Generally, nanotechnology is used alongside molecular biology to transform gene editing, diagnostics, imaging, and drug delivery. It offers the latest platforms improving precision, efficiency, and safety that are catalysts of progress in the fields of medicine, agriculture, and biotechnology (Burbano et al., 2024; Xu et al., 2021; Hu et al., 2024).

Biomedical Applications of Nanotechnology

Nanotechnology is emerging as another element in the fields of biomedical application and has provided new opportunities in drug delivery, tissue engineering, diagnostics, imaging, and biosensing. Examples of nanoparticles that are used in nanotechnology-based drug delivery systems include dendrimers, liposomes, polymeric carriers, and nanoparticles made of gold. Passive targeting is achieved by exploitation of the enhanced permeability and retention (EPR) effect in tumors, active targeting is achieved using ligand-functionalized nanoparticle which specifically bind diseased cells to increase medicinal efficacy and reduce side effects. Controlled drug release systems utilize nanoscale carriers to maintain and control drug release kinetics, minimize drugs degradation, and drug toxicity as well as enhance patient compliance (Tiwari et al., 2023; Kazi et al., 2025; Shang et al., 2023). Nanomaterials find application in the tissue engineering in nanostructured scaffolds, which resemble the extracellular matrix, which offer mechanical strength and biochemical signals required to attach, proliferate, and differentiate cells. High surface to volume ratios, levelable degradation rates together with compatibilities to cell signaling pathways are achieved by nanofibers, nanocomposites and other nanoscale constructs, which arise in regenerating bone, cartilage, skin and neural tissues. Such scaffolds help to better cellular microenvironment and enhance tissue healing and normal functionality (Anbazhagan and Mahalingam, 2025; Matic et al., 2023; Shang et al., 2023). In the field of diagnostics and imaging, nanotechnology promotes the application of fluorescent semiconductor quantum dots in image development, that allows a high-resolution, real-time imaging with size-tunable optical characteristics, as opposed to conventional dyes, such as photostability and multiplexing properties. Gold and silver metal nanoparticles are used as contrast agents in the imaging modalities because of their high plasmonic resonance, and they improve signal strength to ultimately identify and track disease. Molecular imaging and theranostics are also provided by radiolabeled nanomaterials allowing to localize and treat diseases, such as cancer, with great precision (Ray and Bandyopadhyay, 2021; Pijeira et al., 2022). The biosensors based on nanotechnology are developed by using the (a) improved surface-to-volume ratios of nanomaterials and (b) fine-tuned physicochemical attributes to form high sensitivity and selectivity detection platforms. These biosensors use either electrochemical, optical, solid-state, or DNA-based technologies and in their application are used in the diagnosis of early signs of disease, biomarkers or personalized therapy management. Biosensor design with metal nanoparticles, carbon nanomaterials, and quantum dots has demonstrated considerable enhancement in the performance of biosensors, with sensitive and remote healthcare being realized by

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them (Goswami et al., 2024; Silva et al., 2023; Weerarathna et al., 2024). Overall, nanotechnology has provided radical biomedical applications, involving the use of multifunctional nanomaterials in targeted and controlled drug delivery, regenerative tissue scaffolding, advanced biomedical diagnostic imaging using quantum dots and metal nanoparticles, and sensitive biosensing systems. All of these innovations have made important contributions to the field of personalized treatment and precision medicine by providing greater opportunities to optimize the consequences of treatments, preventing addiction to the highest levels of toxicity, and making it possible to detect diseases at an early stage (Kazi et al., 2025; Tiwari et al., 2023; Matic et al., 2023; Goswami et al., 2024).

Therapeutic Applications of Nanotechnology

One of the main types of products of nanotechnology is in the treatment sphere where the small fabricated entities have been found to be useful in a variety of serious medical conditions, but especially in cancerous disorders, cardiovascular conditions, neurodegenerative disorders and antimicrobial/antiviral therapy. Different nanoparticles including liposomes, dendrimers, and polymeric carriers have been used in nanomedicine in the treatment of cancer by facilitating the delivery of chemotherapeutic agents to the area of cancer. This is a specific strategy that promotes drug bioavailability and efficacy and reduces systemic toxicity. The high level of nanotechnology also makes it possible to detect cancer at an early stage by using quantum dots and nanosensors to detect the presence of cancer-related biomarkers. Further treatment modalities such as photothermal therapy, gene therapy and immunotherapy have been added and administered through multifunctional nanocarriers. Controlled drug release and combinatorial treatment Conjugated nanomedicines enable better patient results and precision treatment, which can be improved by controlled drug release and combinatorial approaches (Chakraborty et al., 2022; Zhu et al., 2025; Zhao et al., 2022; El-Meligy et al., 2024; Tiwari et al., 2023). In the context of cardiovascular therapy, nanotechnology can be used to provide breakthroughs in the early diagnosis, imaging, and treatment. Nanoparticles enable targeted delivery of drugs and genes to the cardiac tissues to address the problem of bioavailability and solubilities. Nanoparticles made out of metal i.e., gold, silver, and iron are used as theranostic agents to improve and enhance imaging and offer therapeutic capabilities i.e. targeted drug delivery, and photothermal therapy. Tissue regeneration using nanomaterials is also used to repair heart, especially cardiovascular. Regardless of the promise, issues of immunogenicity and cytotoxicity should be taken into consideration to make sure that the safety and efficacy are guaranteed (Shariati et al., 2023; Udriste et al., 2024; Ray and Bandyopadhyay, 2021). Nanoparticles have the ability to bypass the blood-brain barrier in neurodegenerative disease therapy to transport neuroprotective drug into the brain, and this increases treatment response. Nanotechnology can also be used to aid in early diagnosis by detection of disease biomarkers and has the potential of reducing pathological protein aggregation and oxidative stress which are some of the characteristic features of neurodegenerative disorders. Antimicrobial and antiviral nanoparticles such as metal oxide and metal (including silver, gold and zinc oxide) have been described to have a broad spectrum of activity against bacteria, fungi and viruses. They find their use in

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the topical application and coating, and hydrogels in order to facilitate wound healing and prevent infections including those that are resistant to the conventional treatment. The safety issues of cytotoxicity and genotoxicity are also determined by the properties of nanoparticle preparations, which require full evaluation of toxicity to be used in a clinical setting (Medic et al., 2024; Ray and Bandyopadhyay, 2021). Altogether, therapeutics through nanotechnology avenues offer precision medicine technologies that offer better precision, fewer side effects, and new treatment modalities to major diseases. Current studies are oriented at development of clinical translation addressing such issues as biocompatibility, toxicity, and regulatory approval to realize the full potential of nanomedicine (Jia et al., 2023).

Case Studies and Recent Advances

Newer developments in nanotechnology have made discoveries across a wide area that encompasses plant-derived nanomaterials and DNA nanotechnology as well as biomedical uses. Breakthrough innovations deal with the creation of intelligent nanomaterials with increased physicochemical capacities including tuneable plasmonic properties, quantum characteristics and reversible environmental sensitivity. These intelligent nanomaterials mitigate the weaknesses of traditional nanodevices, including their lack of biocompatibility and their rapid elimination, and are thus very promising on biomedical uses such as controlled drug delivery, targeted therapy, imaging, and biosensing (Aflori, 2021; Silva et al., 2023). Improvements in the plant-based nanomaterials indicate the growing use of metallic nanoparticles that are being produced utilizing plant extracts, presenting eco-friendly, sustainable pathways to the production of nanomaterials with biomedical uses. They are bioinspired nanostructures that are promising in drug delivery, imaging, and antibacterial therapy, and more efforts are being undertaken to address key associated issues of bio-safety and bio-compatibility (Trivedi et al., 2022). DNA nanotechnology has advanced to an advanced level including self-assembled programmable 2D and 3D DNA nanostructures to be deployable and highly addressable biocompatible platforms. Such functionalization with small molecules, proteins and polymers further improves the structural stability, cellular take-up, and targeting of DNA nanostructures, thereby making such nanostructures relevant in drug delivery, biosensing and bioimaging. Plasmonic biosensors also combine with DNA nanotechnology that can be used to create a highly sensitive and selective detection platform using multifunctional bioprobes and DNA origami structures (Henry and Stephanopoulos, 2021; Park et al., 2022; Shishparenok et al., 2023). There are several examples of notable biomedical case studies which reveal the applicability of fluorescent nanomaterials including semiconductor quantum dots, carbon dots, and noble metal nanoparticles in improving the bioimaging and fluorescence-based detection techniques. Genetic engineering The nanomaterials used in cancer therapy have taken the form of reactive oxygen species (ROS)-generating, allowing cancers to utilize oxidative stress-induced by focused targeting. The drug delivery systems which are based on nanomaterials have been shown to be more therapeutically effective as well as less toxic in the case of many disease models and even in the case of orthopedic use. The attainment of renewable resource-related nanomaterials aimed at safe and high-performance biomedical applications is also a consequence of the

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issue of sustainability (Xiao et al., 2021; Li et al., 2021; Guven, 2021; Zhang et al., 2023). To conclude, the recent case studies and technological development in the nanomaterial synthesis show a synergy of smart nanomaterial design, sustainable plant-based synthesis, DNA nanotechnology innovations, and effective biomedical applications. These innovations provide the opportunities of next-generation diagnostics, focused therapeutics, and multifunctional nanodevices with enhanced safety and efficacy profiles (Henry and Stephanopoulos, 2021; Trivedi et al., 2022; Aflori, 2021; Xiao et al., 2021).

Challenges and Limitations

Some of the challenges and limitations of nanotechnology are complex and include toxicity and safety properties, ethical and regulatory concerns, scalability of production, and environmental risks. The issue of nanoparticles toxicity and the OEL are still main because the nanoparticles may be cytotoxic and genotoxic with regard to their size, shape, concentration and composition. Indicatively, although copper and copper oxide nanoparticles demonstrate a great biomedical promise, their biocompatibility and the controlled release are challenging issues that would be evaluated by evaluating the toxicity issues comprehensively before being used in a clinic. Unless it is properly tackled by paying attention to designing and testing, nanoparticle toxicity and how they interact with biological systems can be a hindrance to clinical translation (Gelaye and Luo, 2025; Wozniak-Budych et al., 2023; Zhu et al., 2025). Biodegradable nanomaterials with stimuli-responsive applications to targeted drug delivery should reduce systemic toxicity although their scalability and safety measures need to be assessed existently (Parvin et al., 2025). Nanotechnology is emerging at a fast rate, and ethical, legal, and regulatory matters are emerging due to safety protocols that should be standardized. Regulatory frameworks are are finding it difficult to keep abreast with the currently changing nanoscale materials, which makes it difficult to approve them particularly use in biomedical applications. Research, industry, and regulatory agencies are important to come up with thumbs that allow safe and ethical development of such databases in terms of privacy, informed consent, and fair access (Kumar et al., 2024; Godja and Munteanu, 2024). The challenge of reproducing nanomaterials synthesizing them at scale with consistent size, morphology and functionalization has been a difficulty in large-scale production. The concerns that are going on are stability in production, cost-effectiveness and integration of green synthesis methods. The fundamental focus of research on manufacturable and greener removal processes is needed to attain nanoparticle stability and reproducibility, which are crucial to commercialization and clinical usability (Gelaye and Luo, 2025; Mehejabin et al., 2024; Godja and Munteanu, 2024). The environmental and ecotoxicological risks are concerned with effects of nanomaterials that are emitted into the ecosystem. Nanoparticles are also found to accumulate in the soil and water and long-term impact on plants, animals, and humans is not well understood. In order to reduce environmental impact and toxicity, sustainable nanotechnology and green-synthesized, biodegradable nanomaterials are hoped. Nevertheless, environmental risk assessment and regulation are also in the process of changes through which to effectively deal with these concerns (Gelaye and Luo, 2025; Kumar et al., 2024; Herrera-Rivera et al., 2024).

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Finally, the responsible development and the successful implementation of nanotechnology in industries is possible through environmental risks reduction, setting solid ethical and regulatory frameworks, surmounting the difficulties with the upscaling of production, and addressing general issues of nanoparticle toxicity (Godja and Munteanu, 2024; Kumar et al., 2024; Wozniak-Budych et al., 2023).

Future Perspectives and Opportunities

The new directions and groundbreaking potentials, in particular, the combination with personalized medicine, artificial intelligence (AI), and the interdisciplinary studies, determine the future outlook of nanotechnology. New opportunities are viewed in the form of the new systems of drug delivery that now allow to provide the targeted therapy at least with fewer side effects, in such disease categories as cancer, cardiovascular, neurological. Responsible nanomaterials A responsive nanomaterial is a type of nanotechnology that is being designed to react to environmental stimuli and has numerous applications including diagnostics, imaging and therapies. Sustainable nanotechnology emphasizes on environmentally friendly nanomaterials that meet international sustainability objectives, whereas nanorobotics is offering non-invasive surgeries and rising treatment accuracy (Elzein, 2024; Aflori, 2021). Nanotechnology aids customized therapeutic strategies in the personalized medicine along with the provision of diagnostic tests at a nanoscale and the identification of biomarkers more effectively. Therapeutic-diagnostic nanocarriers are those that perform diagnostic and therapeutic roles simultaneously, which provides the opportunity to monitor real-time treatment progress and make adjustments to the treatment plan depending on the characteristics of each patient (Egorov et al., 2021; Shirzad et al., 2025). The integration of AI is enhancing nanotechnology via processing of large quantities of biomedical data, optimization of nanomaterial design through enhanced functionality and safety, and by means of better clinical decision-making. AI-based algorithms can also complement diagnostics, prognosis, and personalized treatment plans and collaborate with nanotechnology to expand the limits of precision medicine (Tripathy et al., 2024; Shirzad et al., 2025; Bhangle, and Telange, 2025). The interdisciplinary research encourages collaboration among many different fields such as chemistry, biology, materials science, medicine, robotics and computer science to overcome nanotechnology innovations into practical uses. This also entails development of regulatory and ethical systems that deals with safety, standardization and fair access. The intersection of nanotechnology into other disciplines will address such issues as health care disparities, environmental sustainability, and food security to achieve global well-being (Egorov et al., 2021; Elzein, 2024; Ahmed et al., 2021). Essentially, the future place of nanotechnology is the collaboration with AI, individualized practices, and/or cross-disciplinary work, which presents enormous potential that can transform the worlds of healthcare, the environment, and sustainable development.

Conclusion

Nanotechnology has become a revolutionary technology in the interjection of molecular biology and biomedical engineering, and it has initiated a radical change in the study, diagnosis and treatment of biological systems on a molecular platform. This review allows identifying nanoparticle-mediated gene delivery, CRISPR/Cas-based

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genome editing, as well as molecular diagnostics as well as advanced biomedical nanoinformatics such as targeted drug delivery, tissue engineering, bioimaging, and biosensing as the evocative uses of nanotechnology. Nanoscale can also be used to afford new levels of precision, efficiency and control in biological manipulation and in treatment by utilizing unique nanoscale properties such as increased surface reactivity, quantum effects and programmable functionality. Nanotechnology in molecular biology has greatly contributed to genetic engineering, biosensing and imaging because it is not limited in anything as compared to the traditional tools that are used, especially in the extent of delivery, sensitivity, and specificity. Genome editing Major discoveries in the medical and agricultural systems Nanoparticle-mediated CRISPR delivery and DNA nanostructures. On the same note, nanotechnology has transformed the field of biomedical engineering into smart, targeted, and stimuli-responsive nanocarriers and biomimetic scaffolds that enhance treatment effects and reduce toxicity. In spite of these achievements, clinical and industrial translation of nanotechnology is still threatened by concerns of bio compatibility, long-term toxicity, environmental effects, complexity issues of regulations and standard-scale manufacturing reproducibility. To overcome the challenges, it is important to have a strong interdisciplinary work, standardized safety tests and creation of bio degradable and sustainable nanomaterials. In the future, nanotechnology needs to be integrated with artificial intelligence, personalized medicine, and bioinformatics to help speed up the development of safer, smarter and tailored-to-patient nanoplatforms. The ongoing developments in the area present a tremendous potential of precision medicine, detection of diseases early and the development of therapeutics of the next generation. Finally, innovative ideas and care ethics will ensure that nanotechnology potentials are fully achieved to enhance healthcare and advance the living standards of people worldwide.

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