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## Nanoelectronics and Nanomedicine

### Abstract

Nanotechnology is revolutionizing medicine by providing highly accurate diagnostics, targeted therapies, and personalized healthcare solutions. Nanotechnology is redefining medical science through innovations in diagnostics, precision medicine, and advanced therapies. Compact, portable systems now allow for real-time analysis of minimal biological samples, dramatically reducing the time required for diagnosis. As biosensor technologies advance, their sensitivity and ability to process larger volumes of data will continue to enhance early disease detection. Formulations using iron oxide particles and functional polymers have significantly improved imaging quality, even at lower doses, thereby reducing patient exposure to contrast agents while increasing diagnostic accuracy, particularly in the detection of genetic diseases and malignancies.

Nanotechnology is also contributing to regenerative medicine, antimicrobial therapies, wearable devices, and theranostics, which integrate treatment and diagnosis into single systems. Cutting-edge innovations such as nanobots and smart nanosystems are further expanding these capabilities, enabling sensitive drug delivery and minimally invasive interventions. Despite its great potential, nanomedicine faces challenges such as biocompatibility, environmental safety, manufacturing scalability, and regulatory oversight. Addressing these issues is essential for clinical translation and public acceptance.

In summary, nanotechnology offers transformative tools that are reshaping medical diagnostics, therapy, and disease prevention. Through continued research and interdisciplinary collaboration, it has the potential to significantly improve treatment outcomes, reduce healthcare costs, and usher in a new era of precision and personalized medicine.

With the extraordinary advances in nanotechnology, nanomedicine, the application of nanotechnology in the medical field, has made tremendous progress over the past three decades. The field of nanomedicine merges the physical, chemical, biological, and digital worlds together and creates huge potential for solving challenges in numerous medical and health-related issues. From bench-top science research to clinical applications, nanomedicine has demonstrated itself a powerful option in multitude areas and is promising to change the landscape of modern medicine in all aspects, including drug delivery, in vivo imaging, in vitro diagnostics, tissue regeneration and engineering, wearable devices and implants, etc.

**Keywords:** *nanomedicine, therapy, biosensor, bioactivity, nanobots*

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## Nanoelektronika və Nanotibb

### Xülasə

Nanotexnologiya yüksək dəqiqlikli diaqnostika, hədəflənmiş terapiya və fərdiləşdirilmiş səhiyyə həlləri təmin etməklə tibbdə inqilab edir. Nanotexnologiya diaqnostika, dəqiq müalicə və qabaqcıl terapiyalardakı innovasiyalar vasitəsilə tibb elmini yenidən müəyyənləşdirir.

Kompakt, portativ sistemlər artıq minimal bioloji nümunələrin real vaxt rejimində təhlilinə imkan verir və diaqnostika üçün tələb olunan vaxtı kəskin şəkildə azaldır. Biosensor texnologiyaları inkişaf etdikcə, onların həssaslığı və daha böyük həcmdə məlumatları emal etmək qabiliyyəti erkən xəstəliklərin aşkarlanmasını artırmağa davam edəcək. Dəmir oksid hissəciklərindən və funksional polimerlərdən istifadə edən formulalar, hətta daha aşağı dozalarda belə, görüntülmə keyfiyyətini əhəmiyyətli dərəcədə yaxşılaşdırıb və beləliklə, xüsusilə genetik xəstəliklərin və bədxassəli şişlərin müəyyən edilməsində diaqnozun dəqiqliyini artırarkən xəstələrin kontrast maddələrə məruz qalmasını azaldır.

Nanotexnologiya həmçinin müalicə və diaqnozu vahid sistemlərə inteqrasiya edən regenerativ tibb, antimikrob terapiyalarına, geyilə bilən cihazlara və teranostikaya da töhfə verir. Nanobotlar və ağıllı nanosistemlər kimi qabaqcıl innovasiyalar bu imkanları daha da genişləndirir, dərmanların həssas çatdırılmasını və minimal invaziv müdaxilələri təmin edir. Böyük potensialına baxmayaraq, nanomedicin biouyğunluq, ətraf mühit təhlükəsizliyi, istehsalın miqyaslılığı və tənzimləyici nəzarət kimi çətinliklərlə üzləşir. Bu məsələlərin həlli klinik tərəcəyə və ictimaiyyətin qəbulu üçün vacibdir.

Xülasə, nanotexnologiya tibbi diaqnostika, terapiya və xəstəliklərin qarşısının alınmasını yenidən formalaşdıran transformativ vasitələr təklif edir. Davamlı tədqiqatlar və fənlərarası əməkdaşlıq vasitəsilə müalicə nəticələrini əhəmiyyətli dərəcədə artırmaq, səhiyyə xərclərini azaltmaq və dəqiq və fərdiləşdirilmiş tibbin yeni bir dövrünə başlamaq potensialına malikdir.

Nanotexnologiya sahəsindəki fəvqəladə irəliləyişlərlə yanaşı, tibb sahəsində nanotexnologiyanın tətbiqi olan nanotibb son üç onillikdə böyük irəliləyişlər əldə etmişdir. Nanotibb sahəsi fiziki, kimyəvi, bioloji və rəqəmsal dünyaları birləşdirir və çoxsaylı tibbi və səhiyyə ilə bağlı məsələlərdə problemlərin həlli üçün böyük potensial yaradır. Ən yüksək səviyyəli elmi tədqiqatlardan tutmuş klinik tətbiqlərə qədər nanotibb özünü bir çox sahədə güclü bir seçim kimi göstərmiş və dərman çatdırılması, in vivo görüntülmə, in vitro diaqnostika, toxuma bərpası və mühəndisliyi, geyilə bilən cihazlar və implantlar və s. daxil olmaqla, müasir tibbin mənzərəsini bütün aspektlərdə dəyişdirməyi vəd edir (Gu, N. (Ed.). 2023).

*Açar sözlər: nanotibb, terapiya, biosensor, bioaktivlik, nanobotlar*

## Introduction

Research in medicine is to a great extent directed toward developing and improving disease detection and therapy. The use of nanotechnology in medicine, called nanomedicine, has been proposed as a solution to overcome intrinsic limitations in conventional approaches and would allow more effective and safer disease diagnosis and treatment. Furthermore, nanomedicine could play an important role in personalized treatment approaches, which benefit the treatment of diseases with varying representations among individuals and tackles patient variability in therapeutic responses. This is attributed to the unique chemical, physical, and biological properties of the nanomaterials compared to their molecular and bulk counterparts. Of specific relevance in nanomedicine are magnetic nanoparticles (MNPs) that have the additional benefit that they can be remotely detected and controlled by applying external magnetic fields. Because of these advantages, MNPs have been successfully employed in a broad range of biomedical applications (Coene, & Leliaert, 2022).

### Research

Nanotechnology is widely used in many different fields of science today due to its significant benefits in terms of improving performance in many areas. Various types of nano-sized structures, including nanorods, nanowires, nanotubes, nanobelts, nanoribbons, nanofibers, nanoparticles, quantum dots, and hollow spheres, have been developed to advance nanotechnology strategies.

This article explores the diverse applications of nanotechnology in medical fields such as oncology and infectious disease control. Engineered nanoparticles (NPs), such as liposomes, polymer carriers, and carbon-based nanomaterials, enhance drug solubility, protect therapeutic agents from degradation, and provide site-specific delivery, thereby reducing toxicity to healthy tissues. In

diagnostics, nanosensors and contrast agents enable ultra-sensitive detection of biomarkers, supporting early diagnosis, and real-time monitoring.

Nanomedicine is the application of nanotechnology to the medical field. Nanotechnology is a field of technology that studies matter at the molecular level and aims to manipulate this matter for various purposes.

As a specific application of nanotechnology in healthcare, nanomedicine has emerged to provide new solutions to unsolved medical problems. In this regard, nano-based materials are used in a variety of medical settings, including the diagnosis and treatment of various diseases, as well as in tissue engineering and regenerative medicine strategies. Nanoscience and nanotechnology are transforming a wide range of products and services with the potential to improve medical practice and improve public health. Nanotechnology encompasses a broad field of science and engineering focused on the understanding and manipulation of matter at the atomic and molecular scale (Ahmed, 2021). It mainly involves the design, development, and deployment of materials and devices whose dimensions are measured in nanometers. The theoretical basis of this field was first introduced in 1959 by physicist Richard Feynman, who envisioned the manipulation of individual atoms and molecules to create new materials and technologies. Since then, nanotechnology has developed rapidly and is now considered one of the most transformative scientific advances of the 21st century, especially in the field of medicine. In the past few decades, the potential of nanotechnology to revolutionize healthcare has attracted increasing attention, resulting in significant investment and research globally (Wang, Atluri, Tiwari, Babu, 2023). The profound impact of nanotechnology is spreading across industries and promises to reshape the way we approach treatment, diagnosis, and prevention of disease (Yang, Horwitz, 2017).

With nanotechnology, a new frontier in medical science has emerged, enabling precise interventions at the cellular and molecular levels. Engineered nanomachines and nanoscale systems are currently being explored for their ability to monitor, repair, and protect biological systems in unprecedented ways. These innovations aim to reshape traditional medicine and improve human health and longevity.

Nanomedicine is a relatively new field of science and technology. It looks sometimes ill defined and interpretations of that term may vary, especially between Europe and the United States. By interacting with biological molecules, therefore at nanoscale, nanotechnology opens up a vast field of research and application. Interactions between artificial molecular assemblies or nanodevices and biomolecules can be understood both in the extracellular medium and inside the human cells. Operating at nanoscale allows to exploit physical properties different from those observed at microscale such as the volume/surface ratio. (Patel, Patel, & Rai, 2021).

### **Materials and methods**

Nanotechnology has had a profound impact on the life sciences. It has enabled advances in various areas of healthcare, from early disease detection to the development of vaccines and minimally invasive surgical tools. The ability to manipulate matter at the molecular scale has ushered in a new era of personalized medicine, where therapies can be tailored to an individual's genetic and cellular profile (Fahim, Ragab, Hasani, El-Khawaga, 2025).

Nanotechnology applications in healthcare span a wide spectrum. In particular, nano-based therapeutics hold promise in increasing the bioavailability of drugs, minimizing side effects, and improving targeted drug delivery. For example, the blood-brain barrier, which acts as a selective gate to the brain, has traditionally posed a challenge to drug delivery. However, specially designed nanoparticles can now cross this barrier and offer new treatment strategies for neurological diseases. Traditional treatments for diseases such as vascular thrombosis often suffer from limitations including short circulation times and adverse effects. Nanotechnology-based delivery systems such as polymeric nanoparticles and liposomes can encapsulate drugs to enhance stability and therapeutic efficacy. These carriers are biocompatible and biodegradable, making them ideal candidates for advanced drug delivery applications. Nanomedicine represents a transformative frontier in medical sciences and harnesses the precision and power of nanoscale technologies to treat complex diseases such as cancer, cardiovascular diseases, and a number of other serious health problems.

With recent advances in nanotechnology, clinicians and researchers are now able to target biological processes in the human body at an unprecedented molecular level using materials such as biocompatible nanoparticles and nanoscale robotic devices. The integration of nanotechnology has significantly expanded the scope and commercial potential of the nanoscale, offering tools such as nanosensors and nanomachines that are capable of assessing biochemical activities in organs and accessing diseased tissues with remarkable precision.

One of the main strengths of nanomedical systems is the ability to protect therapeutic agents from degradation, thus prolonging their bioactivity and increasing their water solubility. This protection ensures that drugs reach their targets intact and remain effective in the harsh internal environment of the body.

In diagnostics, nanoparticles serve as powerful tools for detecting biomarkers, including those associated with tumors and genetic diseases, and allow for earlier and more accurate diagnosis. The applications of nanomedicine cover a wide spectrum, from traditional chemotherapy and biological agents to new generation immunotherapies (Rokunuzzaman, 2024). Nanostructured carriers can be engineered to recognize disease-specific molecular signals, facilitating highly selective targeting that minimizes damage to healthy cells. This has proven particularly effective in oncology, where nanocarriers increase drug delivery efficiency while reducing adverse side effects.

Nanotechnology is rapidly transforming modern healthcare, shifting the focus from reactive treatment to proactive healthcare management. One of its key strengths is its ability to deliver precise therapeutics, significantly reducing the risk of unexpected side effects while also improving overall treatment outcomes. Its precision-based approach has shown great promise in the management of complex diseases such as cancer, where precise targeting is essential. Among the most innovative advances is the integration of nanorobots into medicine, which facilitate a wide range of applications. These range from targeted drug delivery and smart diagnostic systems to the development of next-generation vaccines and antimicrobial solutions.

Nanotechnology is also contributing to the evolution of wearable health monitoring devices and advanced imaging platforms. The energy gap between traditional pharmaceutical therapies and nanotechnology is paving the way for a new era of combination therapies that can cross physiological barriers such as the blood-brain barrier and act directly at disease sites with high specificity. As a result, even long-standing drug classes are being revitalized through nanoscale delivery systems that increase efficacy and reduce systemic toxicity. Ongoing advances are also paving the way for personalized medicine strategies, where drugs and diagnostics can be specifically designed based on an individual's unique biological profile.

Through the controlled use of engineered nanomaterials such as manganese-citrate complexes, researchers are creating highly efficient drug carriers and diagnostics that operate at the molecular level.

The integration of advanced nanomaterials with precise fabrication and characterization methods enables the development of innovative nanoelectronic devices and effective nanomedical solutions. These materials and methods form the foundation for next-generation technologies in electronics and healthcare.

## Conclusion

In conclusion, nanomedicine represents a transformative force in healthcare innovation. Its ability to redefine disease detection, intervention, and prevention holds significant promise for improving global health outcomes and shaping the future of medical science. Nanotechnology holds the promise of democratizing healthcare by making diagnostics and treatment more accessible and cost-effective. With its expanding applications in clinical areas such as minimally invasive surgery, chemotherapy, and organ regeneration, nanomedicine has significant potential to improve patient outcomes while reducing healthcare costs. As regenerative technologies advance, affordable artificial tissues and organs, such as skin grafts and bone implants, are gradually entering the clinical landscape.

Nanoelectronics and nanomedicine represent two of the most rapidly advancing and interconnected fields in modern science and technology. By operating at the nanoscale, both disciplines enable unprecedented control over materials, devices, and biological systems.

Nanoelectronics has significantly contributed to the miniaturization and performance enhancement of electronic components, leading to faster, more efficient, and energy-saving devices. At the same time, nanomedicine has revolutionized healthcare by introducing innovative approaches for disease diagnosis, targeted drug delivery, imaging, and therapy—particularly in complex conditions such as cancer.

The convergence of these fields opens new possibilities, such as smart biomedical devices, nanosensors, and implantable systems that can monitor and treat diseases in real time. Despite these promising developments, challenges remain, including issues related to biocompatibility, toxicity, ethical considerations, and large-scale production.

In conclusion, nanoelectronics and nanomedicine are shaping the future of technology and healthcare. Continued interdisciplinary research and responsible development will be essential to fully realize their potential and ensure their safe and effective application for the benefit of society.

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