Integrating Nanotechnology and Biotechnology in Holistic Health: New Frontiers in Therapeutics

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Abstract

Nanotechnology and biotechnology are transformative fields that offers a prime potential for providing advancement in health and therapeutics. Nanotechnology involves application of tools that allow for direct control of materials at the atomic or molecular level by modifying such substances that can be used to create drug delivery systems at the nanoscale, nanoscale diagnostic or therapeutic agents. On the other hand, biotechnology utilizes the biological components of living organisms to provide treatments as gene therapies, recombinant proteins and vaccines. Integration of nanotechnology with biotechnology marks the key trend of the today's medical world that led to the age of precision medicine where the concept of targeted drug delivery system to improve the effectiveness of the treatment while minimizing side effects. Nanobiotechnology has applications of curing ailments as cancer, neurodegenerative disorders as well as some infectious diseases. Nanobiotechnology, this cross-disciplinary approach presents the possibility of introducing a new therapeutic method that could revolutionize total health care and result in better care of patients all over the world. This chapter will analyze the close connection between these two crucial fields and will focus on innovative strategies that address critical challenges in medical science.

Keywords: Nanotechnology, Biotechnology, Nanobiotechnology, Therapeutics, Holistic health, Gene therapy

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Introduction

Holistic health appears frequently in the literature that has a wide range of implications. A person is considered healthy if he is free from mental as well as physical disorders (Akyildiz et al., 2015). In order to improve health and reduce illness, it aims to maintain a balance of the entire living organism (Levine et al., 2022). Holistic health is frequently considered as a substitute to traditional drugs and occasionally coupled with complementary therapies, that's why it is termed as integrated medicine (Song et al., 2022). To create the most effective medical care around worldwide, the modern, updated system of healthcare should aim to integrate the best aspects of whole-person health and traditional care (Levine et al., 2022).

Humans have been studying "nano"-sized existence for a long time and Richard Feynman's 1959 speech at the American Physical Society dinner, "There's plenty of room at the bottom," contained the first scientific report on nanotechnology (Jain & Jain, 2008). Nanoscale research and nanotechnology are predicted to make significant progress in the fields of the agricultural sector, electronics, healthcare, and energy (Ghorbanpour and Hatami, 2015). In addition to detecting a wide range of physical ailments (Akyildiz et al., 2015), it is anticipated that Internet of Bio-Nano Things (IoBNT)-based health care will be used extensively to treat psychological issues as well (Bonoiu et al., 2009). The focus of modern biotechnology on human healthcare extends across decades through research in drugs and diagnoses as well as treatments of different diseases and genetically modified food production alongside genetic therapies. Additionally, the human genome project operates as part of biotechnology to both interpret human genetic code and substitute defective genes. All methods and techniques associated with biotechnology have demonstrated exceptional growth during the recent years. Scientists must continue their major efforts to develop new vaccines and drugs and genetically modified crops as well as resistance against multiple pests through multiple biotechnological approaches (Gupta and Chaphalkar, 2016).

Nanobiotechnology has developed a wide range of fields including drug delivery, diagnostics, therapeutics, regenerative medicine and point-of-care diagnostics (Haleem et al., 2023). It can enable the formulation of innovative nanomedicines with minimum side effects. Furthermore, this innovation has made it practical to use molecular self-assembly to study the overall structure of matter in materials science (Xue and Mansoori, 2010). Lithography, ion exchange, adsorption, drug design, catalysis, composites, and plastics are a few examples of these advanced techniques. The intersection of biotechnology and nanotechnology is a revolutionary area of scientific research, especially in the study of human health. Nanobiotechnology uses the special qualities of nanoparticles to solve problematic issues in the medical field (Malik et al., 2023). Nanobiotechnology provides a better future and has the ability to considerably deal with a number of global concerns, featuring avoidance of illnesses, food availability, and sustainability of the environment (Iqbal et al., 2024). In this chapter, we will discuss the integrative role of nanotechnology and biotechnology to improve the approaches to treatment, diagnostics and healthcare.

Biotechnology in Holistic Health

The concept of biotechnology was first brought into use by Karl Ereky in 1919 (Gupta et al., 2017) and the term refers as the use of biology or molecular engineering to manufacture and deliver biologic products for the treatment of ailments (Evens and Kaitin, 2015). It incorporates virtually all branch of scientific use in different fields as health and food production. It applies the chemical processes occurring in living organisms, molecular biology and the use of cells to provide new methods of production and product development approaches i.e. production of vaccines against diseases, bacteria that are useful in oil spillage cleaning or genetically modified plants (Gupta and Chaphalkar, 2016). Biotechnology today is an essential tool in the gene therapy diagnostics, fabrics and clothing, development of drugs, fish farming, chemical manufacturing, crime scene investigation and much more (Ghaffar et al., 2024). They help in the reduction of food toxins, availability of health related products through disease resistance crops, cloning organs transplantation, high quality food production, transgenic animals, that play useful roles in the survival of humans and ensuring food security for the world population (Awais et al., 2010).

Biotechnology allows industries to create completely revolutionary products at a faster pace, and with lesser time and money (Gupta et al., 2017). Biotechnology is integrated in the healthcare industry through diagnostics test kits as well as biological therapeutics labeled with radioactivity for imaging (Afzal et al., 2016). Immunological assays and DNA based methods, Polymerase chain reaction (PCR) and NAAT along with microarray technology is used in diagnosing different diseases and in identifying gene mutation. Furthermore, the application of biotechnology is useful in the preparation of single cell protein, spirulina, enzymes and solid state fermentation in food processing sector (Gupta et al., 2017).

Genetic Engineering and Gene Therapy

Gene therapy can be defined as a process of genetic enhancement of cells by direct modification of its mutated genes or through site specific planned intervention for therapeutic purposes. This therapy has potential due to the development of vectors to deliver extrachromosomal material to targets cells as facilitated by genetics and bioengineering. One of the important criteria of this technique is the choice of the delivery vehicles usually it includes: plasmids, nanostructures or viruses (Goncalves and Paiva, 2017). Classification of gene therapy depends on the type of disease being treated: genetic or complex acquired conditions, gene delivery system: integrating vs non-integrating and on vector administration: *in-vivo* and *ex-vivo* (Anguela and High, 2019). Gene therapy is mainly practiced in research laboratories all over the world and its use is not limited, it has the potential for the treatment of recessive gene deficiency diseases including hemophilia, muscular dystrophy, cystic fibrosis, sickle cell anemia and other acquired inherited diseases as certain virus infections, as AIDS (Misra, 2013).

Biotechnology in Medicine and Nutrition

Progress in today's biotechnology has reached a level that creates the enabling technologies needed to treat these rare and devastating diseases. Major specific objectives of medical biotechnology are biopharmaceuticals, recombinant vaccines, DNA vaccines, bioinformatics, gene therapy, genomics, proteomics and biomedicines. Ever since the humans' genome was sequenced in 2001 biotechnologists have made tremendous effort in pinpointing specific genes that correspond to certain disorders. Many genes associated with diseases including cardiovascular diseases, cancer, respiratory diseases, mental disorders have been identified. Duchenne muscular dystrophy, Huntington's disease, thalassemia, phenylketonuria, hemophilia, Lesch-Nyhan syndrome and sickle cell anemia are some of the promising candidates for gene therapy (Zand and Narasu, 2013).

Vaccination is one of the most important product of biotechnology and has brought tremendous values to human beings. Vaccines are biological agents formulated to induce immunity so as to make body recognize and destroy the pathogen against which an individual has been vaccinated (Bobbala and Hook, 2016). One of most important weapons at the global level for controlling the spread of communicable illnesses are vaccines. They have been of immense usefulness with the excision of smallpox in 1979, the cattle virus Rinderpest in the year 2011 (Greenwood, 2014). Biotechnology is being utilized in two key ways to enhance human nutrition: through raising crop availability particularly home-grown preferred staple crops in the developing world and through improving the quality of those foods in order to benefit populations in both the developed and the developing world. Crops which have been genetically altered to be immune to local pests are expected to enable even the small holder farmer to increase yields for the same investment in an eco-friendly manner. Furthermore, the existing genetic engineering technologies are being used to introduce vaccines into the foods we eat (Mackey, 2002).

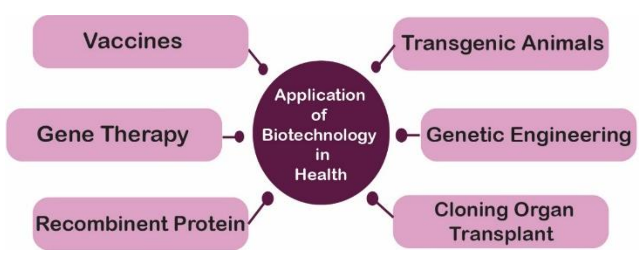

Fig. 1: Applications of Biotechnology in Holistic Health: Vaccines, gene therapy, transgenic animals, recombinant protein, gene engineering and cloning organ transplant.

Nanotechnology in Holistic Health

The science of nanomaterials and nanotechnology offer promise for material engineering and they are now the fastest-growing and most advanced scientific fields. It is the study of managing, constructing, and regulating systems according to their atomic or molecular requirements. Different nanoparticle formulations for medicinal and diagnostic uses have been developed as a result of recent developments in nanotechnology. The purpose of diagnostic nanoparticles is to show diseases and enhance comprehension of significant (pathos-) physiological fundamentals of different illnesses. Many therapeutic nanoparticles are currently used in clinical settings. Some well-known examples of clinically approved therapeutic nanoparticles are Doxil (PEGylated,doxorubicin-loaded liposomes, Janssen, Horsham, PA), Abraxane (paclitaxel-containing albumin nanoparticles, Celgene, Summit, NJ) and AmBisome (liposomal amphotericin B, Gilead, Foster City, CA); numerous other nanomedicine formulations are presently undergoing preclinical and clinical trials (Phillips et al., 2014).

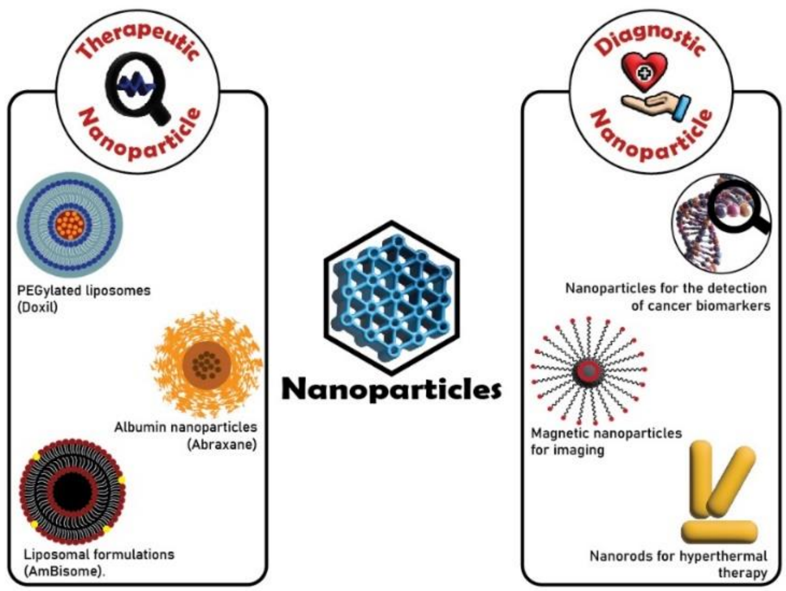

Fig. 2: Therapeutic properties of Nanoparticles: PEGylated liposomes Doxil), Nanoparticles for the detection of cancer biomarkers, albumin nanoparticles (Abraxane), liposomal formulations (AmBisome), magnetic nanoparticles for imaging and nanorods for hyperthermal therapy.

Diagnostic applications of nanoparticles are still trailing behind therapeutic ones. It is an easy way to manipulate the size, shape, and surface functionality of nanoparticles at the nanoscale through recent developments in nanomaterial technology. There are numerous opportunities to use nanomaterials for early cancer diagnosis and treatment because the majority of biological activities, including those linked to cancer, take place at the nanoscale (Lee, 2007). For instance, a variety of hollow nanoparticles particularly liposomes, porous silica nanoparticles, gold nanoparticles, carbon nanotubes and silicon nanowires for the detection of cancer biomarkers, quantum dots and magnetic nanoparticles for in vivo imaging of early-stage tumors and gold nano-shells and nanorods for hyperthermal therapy are among the many engineered inorganic and organic nanomaterials being used in preclinical medicine (Gobin et al., 2007).

Drug delivery nanoparticles are typically less than 100 nm in at least one dimension and are made of many disintegrating substances, including metals, lipids, and natural or manmade polymers. Since nanoparticles are more readily absorbed by cells than bigger micromolecules, they may be employed as efficient delivery and transportation vehicles (Stylios et al., 2005). Drug bioavailability, pharmaceutical targeting, and the absorption of less soluble medications can all be enhanced by the use of nanoparticles in precise drug delivery at the site where disease occurs. Nanomaterials have been successfully used in the preparation of anti-cancer drugs such as doxorubicin, dexamethasone, 5-fluorouracil and paclitaxel (Suri et al., 2007; Salar et al., 2024).

Different nanotechnological approaches including liposomes, liquid crystal (LC) systems, microemulsions, polymeric nanoparticles, solid lipid nano-particles (SLNs) and precursors systems for liquid crystals (PSLCs) have been developed to overcome this interfacial barrier. This multidisciplinary approach to drug formulation is capable of modifying the structural and functional attributes of the drug as well as altering its performance in vivo and these innovations have revolutionized the field of targeted drug delivery. In addition to enhancing the use of active ingredients, the new drug delivery systems can reintroduce other ingredients that were previously removed from the formulation because they were not useful (Mara Mainardes et al., 2006). Moreover, the method is equally more appealing with the possibility of enhancing new compounds before commercialization or therapeutic application, including enhancing selectivity and usage, avoiding thermal or photo degradation, reducing side effects, and controlling the release of active constituents (Bonifacio et al., 2018).

There is an increased demand for tissue engineering and regenerative medicine (TERM) due to the various disadvantages of tissue and organ transplantation, such as the lack of donors, the need for immunosuppression and the low success rate (rejection of the transplant) (Fathi-Achachelouei et al., 2019). The objective of the new broad field of regenerative medicine is to maintain, enhance or restore tissues and consequently the functions of organs. Living cells, which will give biological functioning and materials, which serve as scaffolds to enable cell growth, can work together to regenerate tissues (Engel et al., 2008).

Drug delivery, heart muscle and vascular grafts are a few of the cardiovascular tissue engineering fields for which nanomaterials and nanotechnologies have been extensively examined so far. There are several phases of nanotechnologies of cardiovascular regenerative therapy in this special issue (Omidian et al., 2023). The cardioprotective effect of drugs in patients with cardiovascular disease can be enhanced by nanomaterials that deliver such drugs. There are several applications of nanomaterial-drug delivery systems in cardiovascular imaging and treatment of various cardiovascular diseases (Deng et al., 2020). Cardiovascular diseases are usually diagnosed by biomarkers or molecular imaging (MOI). The sensitivity, specificity and accuracy of the assay in the early stages of cardiovascular diseases remain challenging to attain. Cardiovascular disease (CVD) is presently diagnosed with cardiac biomarkers and imaging methods. The application of various nanotechnologies to improve the efficiency of cardiac immunoassays and molecular imaging to diagnose cardiovascular diseases in their initial stages was also in consideration (Shi et al., 2020).

Overview of Intersection of Nanotechnology and Biotechnology

Biotechnology and nanotechnology are the most remarkable new fields of research in the current century. Nanobiotechnology is the intersection of these two fields of research, which uses both nanotechnology and biotechnology to construct a broad range of applications as well as examine and construct nanobiosystems to address a range of challenges (Amin et al., 2011). The intersection of nanotechnology and biotechnology has revolutionized the scientific research, particularly, in the domain of human health. Materials exhibit specific features at the nanoscale to allow an accurate manipulation and interaction with the biological system, thus creating a variety of possibilities that would assist in dealing with major problems globally (Hassan and Fathi, 2024). Subsequently, nanotechnology and biotechnology work together to transform diagnosis, treatment, and medicine (Podutwar et al., 2024).

Table 1: Applications of Nanobiotechnologies

Nanobiotechnologies	Applications	References
Electrochemical biosensors	Detection of cancer cells	(Karnwal et al., 2024)
Nanosphere's Clear Read	Detection of SNP	(Alharbi and Al-Sheikh, 2014)
Nanoparticles-based liquid biopsy	Detection of ctDNA, circulating tumor cells, protein, peptide, miRNA and exosomes	(Kim et al., 2024).
Nanofluidic Chip	Dignosis of eurological disorders, infectious diseases, cardiovascular diseases (CVDs), and autoimmune diseases	(Kim et al., 2024).
Lab-on-a-chip (LoC) technology	Analyse bacterial,viral, and parasitic diseases	(Rosenberg and Restifo, 2015)
(CRISPR)/Cas9 system	Gene therapy	(Kim et al., 2024).
Nanoparticle-based drug delivery systems	Cancer treatment and transportation of anticancer agents,	(Elumalai et al., 2024).
Nano-stent	Regeneration of islet β cells, retinal tissue, wound tissue and nerve tissue cells	(Li et al., 2022).

Applications of Nanobiotechnology

Recently, nanobiotechnology has been revolutionizing important areas of molecular biology, including cellular and molecular diagnosis and therapy (Mohanty el al., 2009). In comparison to traditional methods, cancer cells can be diagnosed and treated using nanobiotechnologies including biosensors, nano-probes, and contrast enhancers (Sun et al., 2024). In electrochemical biosensors, gold nanoparticles (AuNPs) can be functionalized by binding specific biomolecules, including antibodies, DNA probes, or aptamers, enabling the extremely sensitive and selective detection of target analytes (Karnwal et al., 2024). A microarray-based technique for the detection of numerous single nucleotide polymorphisms (SNP) in complete human genomic DNA is made possible by Nanosphere's Clear Read nanoparticle technology, despite the requirement for target amplification by PCR (Alharbi and Al-Sheikh, 2014). One of the newly emerged techniques, nanomaterial-based liquid biopsy, utilizes optical nanomaterials for the detection of circulating tumor DNA (ctDNA), protein, peptide, miRNA, exosomes, and circulating tumor cells (CTCs) in biofluids, making it possible to detect a wide range of diseases, including cancer. Similarly, nano/microfluidic chip technology is utilized to diagnose neurological diseases, infectious diseases, cardiovascular diseases (CVDs), and autoimmune diseases (Kim et al., 2024). Moreover, most of the bacterial, viral, and parasitic infections such as HIV/AIDS, malaria, and chronic respiratory infections are diagnosed and treated using Lab-on-a-chip (LoC) technology. Furthermore, cancer detection and targeting is achieved by imaging with quantum dots (Chakraborty et al., 2011).

Additionally, in nanobiotechnology nanomaterials can be utilized in particular therapeutic interventions such as photothermal therapy (PTT) and sonodynamic therapy (SDT) that can be applied together with other therapies in order to enhance the efficiency of treatment (Ji et al., 2023). One of the most important part of gene therapy, the gene-editing tool known as the clustered regularly interspaced short palindromic repeat (CRISPR)/Cas9 system utilizes nanomaterials as non-viral vectors for the recognition and cleavage of particular sites of DNA (Kim et al., 2024). Nanoparticle-based drug delivery systems (liposome- or dendrimer-based systems) are utilized in cancer therapy to enhance the delivery of anticancer drugs, minimize widespread toxicity, and enhance the efficiency of treatments (Elumalai et al., 2024). Nanomaterial-based technologies are commonly used to regenerate bones, cartilages, muscle, skin, and teeth. Nanomaterials play a central role in the advancement of regenerative medicine because nanomaterials improve cell adhesion, tissue regeneration, and cell proliferation scaffolds (Fathi-Achachelouei et al., 2019). Besides this, nano-stent is also a potential method for regenerating islet β cells, retinal tissues, wound tissue and nerve tissue cells. Most nanoparticles also accelerate the process of wound healing and provide other benefits that have overcome many issues in the clinical use of regenerative medicine (Li et al., 2022).

Nanobiotechnology is a rapidly growing field that produces new products for a variety of industries by merging the concepts of biology with nanotechnology. Nanobiotechnology has gained considerable interest in the recent times owing to its potential to completely transform the food, pharmaceutical, packaging, nutrition, and agriculture sectors. Promising results in various medical fields including, tissue engineering, and drug delivery medical imaging have been shown by nanobiotechnology. Nanobiotechnology-based antimicrobials have also been developed to combat the increasing problem of antibiotic-resistant bacteria. In short, nanobiotechnology is paving the road for a better future and has the potential to significantly solve numerous global concerns, particularly preventing diseases, food security, and a sustainable environment (Iqbal et al., 2024). On the other side, nanobiotechnology has several constraints including nanoparticles toxicity, potential environmental concerns, relatively inexpensive, and minimal input of energy, that have to be managed (Tripathi and Prakash, 2022).

Challenges and Future Directions

Nanobiotechnology is encountering numerous obstacles that must be overwhelmed. Developing effective tools to measure nanomaterial contact with air and water is one of the main obstacles. To avoid negative effects, human intake of air and water contaminated with nanomaterials must be regulated. This issue becomes more detrimental while discussing the contamination of consumables, such as food items, by nanomaterials. However, it would be unavoidable to do in vivo research using animal models to comprehend how these nanomaterials affect the environment and human health (Qamar et al., 2019). Since nanomaterials are so small (less than 100 nm), they can interact with biological structures such as cell walls, organelles and nucleic acids to influence internal biochemical reactions. This is one of the key issues that can damage healthy and normal cells (Dutt et al., 2022).

Being able to find unique treatment plans for patients with serious medical conditions as cancer, heart disease and neurological disorders will be further improved in the future by the combination of nanobiotechnology with high-throughput genomic sequencing, transcriptomics and proteomics innovations. Specific medical advancements will be triggered by nanotechnology, which will make it possible to create distinct treatment strategies that are specific to each patient's needs and illness. By combining nanotechnology with modern imaging methods and techniques for machine learning, it will be possible to observe the progression of diseases in real time, reveal structural changes and provide personal therapy suggestions, all of which will enhance patient clinical results and standard of life (Qamar et al., 2019).

Studies must also concentrate on raising attention about the development of nanobased diagnostic tools. Nanotechnology related studies in medicine also need to speed up with FDA approval in order for physicians to effectively use in vivo trials as a preventive tool in hospitals. The concept of using herbal nanoparticles to transport chemotherapy medication into a selected tissue may also attract certain possible research teams and have noticeable effects. Thus, the use of "herbal remedies" within Nan-companies will increase their ability to treat a variety of chronic illnesses along with medical treatments (Arulanandraj et al., 2018). Nanobiotechnology has the potential to lead to significant advancements in personal health care in the near future. The accuracy and precision of the examinations could be further improved by employing nanodiagnostics. Accurate illness detection and therapeutic interventions may result from the discovery of novel and more distinctive nanoparticles (Qamar et al., 2019).

Conclusion

In conclusion, the integration of nanotechnology and biotechnology has played a significant role in holistic health and therapeutics. The coordination of these two fields has created opportunities for development of solutions to many health issues. The progressive developments in targeted drug delivery, individualized treatment, and regenerative medicine represent are the most promising ones. Moreover, the ability to manipulate biological systems at the molecular level offers the promise of safer, more sustainable therapies. These innovations could lead to breakthroughs in drug delivery systems, gene therapies, and diagnostic tools as PCR, addressing complex health challenges more effectively than ever before. As research progresses, the synergy between these fields will likely open new frontiers in medicine, leading to transformative approaches for treating a wide range of diseases and promoting overall well-being. This chapter highlights the new frontiers of nanotechnology and biotechnology, the potentials shall be realized as the risks are tempered. The future of holistic health can be without a doubt characterized as rather promising, as these new therapeutic approaches will shape the world's healthier and wealthier future.

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