Nanobiotechnology-Based Approaches in Personalized Medicine

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ABSTRACT

Personalized medicine aims to tailor disease prevention, treatment and diagnosis for specific patients based on their genetic, molecular and phenotypic profiles. The integration of nanotechnology enhances the personalized medicine by enabling precise, targeted drug delivery, specific therapeutic for individual patients. Nanocarriers like nanoparticles, lipid-based nanoparticle, antibody tagged nanoparticles and liposomes profess unique property like controlled drug release, targeted drug delivery and limits non-specific binding. This approach plays a crucial role in genomics-therapy, cancer diagnosis and pharmacogenomics. This review highlights the importance of personalized medicine in nanotechnology, nanomaterial-based therapeutics as a healthcare solution

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INTRODUCTION

Nanotechnology is widely used in personalized medicine for patients with specific health conditions, varied dosage levels and altered environmental settings. This technology prefers a board choice of particles and materials of the size range from 10-100 nm (Alghamdi et al., 2022). Personalized medicine always aims to cure the disease for each person specifically based on their unique genetic makeup, disease variability and metabolic molecular profiles. Understanding that the genetic fingerprint of individuals contributes to the exceptional response in metabolism has paved way for personalized medicine and the initiation of it has brought forth pharmacogenetic testing. Human Epidermal Growth Factor Receptor 2 (HER 2) expression testing has allowed the early detection and identification of breast cancer in females and nanoparticle integrated medicine gives an approach to the personalized medicine (Jain et al., 2005; Yu et al., 2010; Woelderink et al., 2006).

Bridging Nanobiotechnology And Precision Therapy

Nanotechnology plays a pivotal role in bridging the personalized medicine into clinical practice by integrating target drug delivery. Nanocarriers like liposomes, nanoparticles are the source of nanotechnology in personalized treatment (Minko et al., 2013). Lipid nanoparticle, liposomes and sliver nanoparticle are some nanocarrier which are used in cancer treatment for targeted drug delivery of anticancer drug like doxorubicin, SN-38 and paclitaxel. Targeting the chemotherapeutic drugs to the cancer cells has been made efficient and also alleviated the un-specific binding to non-cancer cells reducing the risk of allergic reactions. Therefore, the personalized medicine has enhanced the drug efficiency and reduced toxicity to a greater extent compared to the conventional methods of chemotherapy (Hussein and Abdullah, 2021; Ha et al., 2019; Allahou et al., 2021).

Nano-Biomaterials Used In Personalized Medicine

Nano bioformulations such as liposomes, PEGylated liposomes, polymeric nanoparticles, polysaccharide-based biomaterials, micelles, polymer-protein conjugate, and lipid nanoparticles are currently used as nanomedicine in the pharma industry, for personalized therapy (Koutsopoulos, 2012). These are known to make changes in the active principles of pharmacokinetics and pharmacodynamics (Fornaguera & García, 2017). Usage of nanocarriers in drug delivery has proven to be advantageous. For example, nanocarriers like cationic lipids, polymeric micelles, and inorganic nanoparticles have been formulated to tackle systemic toxicity, low cellular uptake, lysosomal escape, and multidrug resistance effects (Fornaguera & García, 2017; Wang et al., 2018). Apart from these, active nanostructures such as targeted drugs, actuators, amplifiers, and 3D transistors are being used (Calabretta et al., 2020). Three generations of nanomaterials have been classified (1G, 2G, 3G) where the first one is basic nanoparticles, second one is composed of well assembled nano-systems, and self-driven nanodevices come under 3G (Wang et al., 2018).

Nanobiotechnology-Enabled Personalized Therapeutic Strategies

Nanoformulated drugs have several advantages like controlled release, prolonged stability, metabolism, less side effects, prolonged circulation in blood and effective performance. Some of the strategies using nano-biopharmaceuticals enabled personalized therapy are as follows. Intravenous injections help to deliver the formulation to the site directly whereas in other routes, they are able to pass the biological barriers, and are absorbed by cells in order to avoid this encapsulation of drugs can be done which prevents drug degradation, and functionalization with ligands or proteins helps in active targeting (Al-Ghamdi et al., 2022). Smart drug delivery carriers, patient specific nanomaterials, self-assembling peptides, and stimuli responsive nanocarriers are advantageous and have the potential to respond to risks and enable optimal therapy (Koutsopoulos, 2012).

Applications In Personalized Medicine

Nanoparticles and nanofibers are being used for drug delivery, with improved drug delivery efficacy, biodistribution, and diffusivity. In nanoscale, biomaterial scaffolds, nano encapsulation of the biomolecules helps in migration, vascularization, and incorporation of the therapeutic biomaterial into the tissue (Koutsopoulos, 2012). Theranostic nanomedicines are a combination of therapeutics and imaging agents which are delivered in the same nanocarrier, which may help in creating personalized approach in disease management. Nanodevices are also used in MRI, optical imaging, photodynamic therapy, gene therapy, ultrasonography, and chemotherapy (Mura & Couvreur, 2012).

Challenges And Ethical Considerations

Nanotechnology offers transformative potential in personalized medicine by precise unique properties of the nanomaterials, addressing notable challenges in drug delivery and diagnostics. Recent advancement implies challenges including, immunogenicity, issues with scalability and evaluation of long-term biocompatibility (Chattopadhyay et al., 2025). The main subject of discussion is with the safety at biological level, large-scale production and the cost. Similarly, personalized medicine also faces ethical and legal challenges as identification and targeting the genome of an individual would be accessible by many people. Toxicity study in clinical trials may require long period and cannot be accelerated. On the other hand, large scale production would be more difficult because a slight change in the size of nanomedicines may significantly affect the characteristics of the nanomaterials. Manufacturing of nanomedicine also has challenges, as synthesis of nanomedicines often have multiple process for stabilization and standardization, followed by quality control protocols and regulations have a long way to go to make a theory put into practice (Alghamdi et al., 2022; de Souza Cardoso Delfino et al., 2025).

Recent Advances, Future Perspectives And Clinical Translation

Recent advances in nanobiotechnology have multifunctional nanoscale systems for drug delivery, diagnostics, therapeutic monitoring, and immunotherapy, effectively impacting personalized medicine by improved efficacy and reducing side effects. Nanocarriers are being explored in advanced therapeutic applications including cancer treatment, vaccines, and also gene delivery, then some have moved to clinical trials and societal use (Rehan et al., 2024). Personalized medicine applies in various areas of clinical disciplines, such as neurology, anesthesiology, cardiology, etc., (Alghamdi et al., 2022). Despite the advantages, the clinical translation still faces the challenges, such as scalability, evaluation and regulatory approval. Future prospectives emphasize integration of artificial intelligence and 3D models to design and experiment more effective patient-specific diseases alleviation by incorporating nanomedicines and improve their transition from laboratory research preferences to the clinical practice, and enabling them into personalized therapeutics (Chattopadhyay et al., 2025; Silvani et al., 2025).

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