http://pmjournal.ir Review Article
Autumn 2021, Volume 6, Issue 23 (30-34)

The Impact of Nanotechnology on the Future of Personalized Medicine

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DOI: 10.22034/pmj.2021.249632

Submitted: 2021-11-04
Accepted: 2021-12-03

Keywords:
Nanotechnology
Nanomedicine
Personalized Medicine
Nanomaterial
Imaging

Abstract:
Personalized medicine as a revolutionary in medicine provides medical services tailored to a person's molecular characteristics. In personalized medicine, the physician with the knowledge of information in the person's molecular profile (omics) can prescribe an effective drug with minimal side effects and appropriate dose for changing lifestyle and diet to prevent and treat diseases.
Theoretically, the molecular profile of each individual could give some information about risk of diseases, the person responses to medications and the relationship between person molecular profile and certain traits, such as lactose intolerance and diet-specific adaptation.
In the past, it was impossible to confirm the presence or absence of mutations in an individual's genome, as the use of molecular techniques such as PCR was very time consuming and was associated with many limitations. On the other hand, many traits and diseases are multigenic and the consequence of interaction with environment. Furthermore mathematical models for measuring genetic risk were not developed. In recent years, creation of individual genetic profile with determination of a person's genotype and all known mutations in a short time and at low cost became possible, due to advances in microarray technology, computer science and statistics.
In parallel with genomics, advances in other multidisciplinary sciences such as nanotechnology and systematic biology have facilitated the disease interactions at the cellular and molecular scale. Nanomedicine has provided the control of drug release profiles using design and fabrication of nanostructured devices, so it is hoped that by combining these information and examining their interactions, better contribution to human health will be achieved. In this review, we focused on nanotechnology applications and solutions that impact on personalized medicine and accelerate its progress and development.

INTRODUCTION

Nanotechnology and Nanomedicine

Over the past decades, the development of nanotechnology and application of nanoparticles as carriers of small and large molecules has significantly attracted the attention of researchers. Before addressing nanotechnology and nanomedicine, the meaning of terms such as nanotechnology, nanoscience and nanoscale should be clarified (1).

The prefix «Nano» is derived from the Greek word «Nannos» meaning dwarf or an abnormal short human. According to the root of this prefix, the nano is a measurement scale in a metric system and as a scientific unit refers to one billionth (0.000000001) of a base unit, so one nanometer is one billionth of a meter (1m = 10^9 nm) or 1 nm = 10^{-9} m). So, when talking about nanotechnology, a scale of size or a scale of length is considered.

The National Nanotechnology Initiative describes nanotechnology as follows: "Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications". Thus, materials that at least one of their dimensions (length, width, height) are less than 100 nanometers describe to be on a nanoscale. In order to have a more comprehensive definition of nanotechnology, it is better to add these two statements to the previous definition: First, nanotechnology is the fabrication and employment of materials, structures, tools and systems that have unique properties due to their small size. Second, Nanotechnology also includes technologies that make it possible to control materials at the nanoscale (2).

The term of "nanotechnology" has been used more for decades in scientific fields such as electronics, physics and engineering. However, much research has been done in the fields of biological sciences, pharmacology and medicine, in recent years. Nanotechnology is a multidisciplinary field with the convergence of basic and applied sciences such as biophysics, molecular biology and bioengineering. The decrease in size and the consequent special changes that occur in matter have created unique applications in various sciences. The main advantages of reducing the size at the nanoscale are the following: increase in surface to volume ratio followed by increase of surface energy and reactivity and increase solubility and functionality rate (3).

Nanomedicine is the use of nanomaterials and nanodevices for medicine applications. The purpose of this field of nanotechnology is prevention, diagnosis and treatment of diseases in order to improve the human life quality. Nanomedicine includes a wide ranges of applications for examples nano vaccines for prevention of infectious diseases such as covid-19 (Pfizer an Moderna vaccines) (4), nanobiosensors for early and point of care detection of diseases (5), drug delivery nano carriers for cancer therapy (6), nanomaterials for imaging (7), core-shell nanoparticles for hyperthermia and photodynamic therapy (8), nanorobotics for imaging and treatment of atherosclerotic lesions (9), theranostic nanostructures for simultaneous diagnosis and therapy of diseases (10), nanowires for treatment of neurodegenerative diseases (11) and nano scaffolds for tissue engineering and regenerative medicine (12).

The important challenge of nanomedicine is nanomaterial toxicity and their interactions with the body; therefore the researchers in this field use biocompatible and biodegradable material to prevent the body's immune responses.

Nanotechnology and personalized medicine

In the past, the same treatment was used for all patients with the same disease, but today unique personal therapy should be applied according to the unique genome and different living environment of each person. Personalized medicine is a conceptual approach of modern medicine in which prevention, diagnosis, treatment and care of the patient are based on the unique characteristics of the person. In this field, clinical, paramedical, genomic information, patient's lifestyle, the individual›s environmental conditions and the type of disease all lead to the provision of a useful therapeutic solution and provide medical services (health, prevention, diagnosis, treatment and care) appropriate for patient. So, this field of medicine using various sciences of genetics, bioinformatics, biotechnology and statistics has opened a new window for the physician to prescribe an effective drug with minimal side effects and in appropriate doses to change lifestyle and diet to prevent and treat diseases and change traits. The pervasiveness of this medical field leads to the effective, accurate, safe prescription of medicine and the reduction of treatment costs. Although personalized medicine, as an expanding branch of medicine, is several thousand years old, but in recent years, the person-centered approach has gradually spread to all branches of medicine. This branch of science is gaining more and more applications in everyday medicine and seems to be one of the major fields of medicine in the near future.

Advances in other multidisciplinary sciences such as nanotechnology and nanomedicine have facilitated the disease interactions at the cellular and molecular scale. Nanomedicine has provided the control of drug release profiles using design and fabrication of nanostructured devices, so it is hoped that by combining these information and examining their interactions, better contribution to human health will be achieved. Nanotechnology offers material with unique properties and novel approaches for fighting human diseases (13). Here, we describe the nanomedicine approaches in drug delivery, imaging and tissue engineering that impact on personalized medicine.

Targeted drug delivery and personalized medicine

An important issue in cancer therapy and treatment of many other diseases is that the drug does not reach the patient›s tissue in a targeted manner.

From the point of drug injection until finding the target tissue, there are various biological, physical and chemical barriers and obstacles that prevent sufficient drug delivery to affected tissue. Studies show only 1 out of 100,000 molecules of a drug successfully reaches the pathological site. For example, scientists demonstrated that in Kaposi's sarcoma models only ~0.001% of doxorubicin reaches tumor sites. So, a large part of the drug is lost in this way and to overcome these obstacles, the higher concentration of the drug should be administrated. This overdose will be responsible for the side effects of the drug (14).

The important point about these barriers is that they are largely variable from one type to another, from person to person and from a tissue to another tissue, and also change over the time of disease progress, therefore personalized medical treatment strategies should consider these variables.

Nanomedicine offers novel nanoscale platform for targeted drug delivery such as PEGylated liposomal formulation and lipid nanoparticles (15), iron oxide and gold nanoparticles (16), carbon nanotubes and fullerenes (17), silicones (18), mesoporous nanoparticles (19) and polymeric micelles (20) to fight these barriers and efficient delivery of anticancer drugs to pathological sites. For this purpose, the nano carrier's properties such as size, shape, the surface charge, porosity and materials should be optimized.

These multifunctional nano carriers functionalized with moieties such as antibodies (21), aptamers (22) and other ligands for specific targeting of affected cell receptors, coated with biocompatible shielding layer such as polyethylene glycol (PEG) to escape from body's immune system, loaded with drugs and in some cases dyes and fluorescent nanoparticles and molecules for monitoring of drug delivery process and imaging of pathological tissue.

In addition to cancer, diabetes is another important metabolic disease in which nanomedicine has been used. Nowadays, diabetes treatment is an invasive approach, while polymer nanoparticles offer a non-invasive theranostic system called Smart Insulin L-490, which detects the patient's blood glucose concentration and releases insulin in proportion to the glucose level (23).

Disease diagnosis and personalized medicine

According to personalized medicine concept, the response of each patient to medical treatment may be different, so the person's response to particular drug should be tracked during the course of treatment. On the other hand, early detection of many diseases, especially cancers, can have a great impact on the onset and effectiveness of treatment (24).

The main challenges of currently used imaging techniques such as MRI, PET, SPECT and CT scan are the inability to monitor the effect of the drug regularly as well as early diagnosis of the disease (13).

Nanomedicine proposes contrast agent nanoparticles to improve the quality of molecular imaging techniques. High contrast, biocompatibility, tunable physical properties and longevity are the main features of nanoparticles including superparamagnetic iron oxides, liposomes and metal nanoparticles that use in this field (25, 26).

Simple fabrication of multifunctional nanoparticles that can target a specific biomarker and track and treat a disease simultaneously is one of the great aspects of nanomedicine. These platforms are called theranostic agents and play an important role in early diagnosis and real time monitoring of drugs. Noninvasive detection of biomarkers by these nanoparticles provides the regular monitoring of biomarker expression during the treatment of diseases without need to biopsy determines the response of patient to therapy and defines disease progression model (27).

Fluorescent nanoparticles including different types of quantum dots and gold nanoparticles are some nanostructures that have been used for the purpose of diagnosis. Microfluidic devices deploy the interaction of system biology and nanotechnology and physical and chemical properties of liquids and gases in microscale for early detection of disease like cancer (28). Microarray technology also is a lab on a chip system that enables multi detection of analytes. In this technology, biological receptors including lipids, nucleic acids and proteins or chemical molecules immobilize at the surface of a substrate and detection occurs with the use of fluorescent and plasmonic nanoparticles (29).

Tissue engineering and personalized medicine

The role of personalized medicine is important in the field of tissue engineering for regeneration of a tissue or organ transplantation. Transplantation rejection is due to the surface biomarkers and immune response that is related to biological properties of a patient (30). In this field, nanomedicine can introduce nanofiber scaffolds and mesoporous hydrogel for simulation of extracellular matrixes to support the growth of stem cells (31). Carbon nanotubes (32), silicon, hydroxyl apatite nanocrystals (33) and other nanoparticles were incorporated to these scaffolds to improve their properties such as mechanical reinforcement. Magnetic nanoparticles loaded scaffold uses these nanoparticles to direct drug and growth factor to the site of tissue following the induction of a magnetic field (34).

Challenges of nanomedicine toward personalized medicine

As mentioned in section 1, nanomedicine can be used for the progress of personalized medicine and there are many examples of nanomedicine for development of personalized medicine. But there are some challenges in this field:

First, nanoparticles properties including size, shape, material, molecular type, surface charge and hydrophobicity, functional group and surface moieties should be defined.

Nanoparticles toxicity as a second challenge in this field is related to material type. There are many FDA approved materials that can be used in nanomedicine but other materials toxicity should be investigated.

The third issue is the heterogeneity of biological properties of patients. Considering this variability is important to design nanoparticles and surface functionalization of nanoparticles.

The route of administration for better acceptance of patients is another important challenge of nanomedicine. Intravenous administrated nanoproducts aren't patient friendly and should be improved.

Nanomedicine scale up to bring a nano product from lab to market is another important challenge of this field. Cost effectiveness, sterilization and storage issues are followed by nanomedicine scale up.

Despite the difficulties in the development of nanomedicine, the future of this field is very optimistic. Although fewer nanotechnology products have entered the market, research in this area is ongoing and a good future will be ahead. In the future, nanomedicine will make a major contribution to the development of personalized medicine.

REFERENCES

1-Aliyar H. and Schalau G. (2015) Recent developments in silicones for topical and transdermal drug delivery. Therapeutic Delivery 6:827-839.

2- Armstrong J. P. and Stevens M. M. (2019) Emerging technologies for tissue engineering: from gene editing to personalized medicine. Tissue Engineering Part A 25:688-692.

3- Baumann B., Wittig R. and Lindén M. (2017) Mesoporous silica nanoparticles in injectable hydrogels: factors influencing cellular uptake and viability. Nanoscale 9:12379-12390.

4-Choi W. I., Lee J. H., Kim J.-Y., Heo S. U., Jeong Y. Y., Kim Y. H. and Tae G. (2015) Targeted antitumor efficacy and imaging via multifunctional nano-carrier conjugated with anti-HER2 trastuzumab. Nanomedicine: Nanotechnology, Biology and Medicine 11:359-368.

5-Cui H., Yu Y., Li X., Sun Z., Ruan J., Wu Z., Qian J. and Yin J. (2019) Direct 3D printing of a tough hydrogel incorporated with carbon nanotubes for bone regeneration. Journal of Materials Chemistry B 7:7207-7217.

6-Dittler M. L., Unalan I., Grünewald A., Beltrán A. M., Grillo C. A., Destch R., Gonzalez M. C. and Boccaccini A. R. (2019) Bioactive glass (45S5)-based 3D scaffolds coated with magnesium and zinc-loaded hydroxyapatite nanoparticles for tissue engineering applications. Colloids and Surfaces B: Biointerfaces 182:110346.

7- Elingarami S., Li X. and He N. (2013) Applications of nanotechnology, next generation sequencing and microarrays in biomedical research. Journal of Nanoscience and Nanotechnology 13:4539-4551.

8-Emerich D. F. and Thanos C. G. (2007) Targeted nanoparticle-based drug delivery and diagnosis. Journal of drug targeting 15:163-183.

9-Gabizon A. A. (2001) Pegylated liposomal doxorubicin: metamorphosis of an old drug into a new form of chemotherapy. Cancer investigation 19:424-436.

10- Gallo M., Favila A. and Glossman-Mitnik D. (2007) DFT studies of functionalized carbon nanotubes and fullerenes as nanovectors for drug delivery of antitubercular compounds. Chemical Physics Letters 447:105-109.

11- Gautier J., Allard-Vannier E., Munnier E., Soucé M. and Chourpa I. (2013) Recent advances in theranostic nanocarriers of doxorubicin based on iron oxide and gold nanoparticles. Journal of Controlled Release 169:48-61.

12-Hosseini V., Mirrahimi M., Shakeri-Zadeh A., Koosha F., Ghalandari B., Maleki S., Komeili A. and Kamrava S. K. (2018) Multimodal cancer cell therapy using Au@ Fe2O3 core–shell nanoparticles in combination with photo-thermo-radiotherapy. Photodiagnosis and photodynamic therapy 24:129-135.

13-Huang Y., He S., Cao W., Cai K. and Liang X.-J. (2012) Biomedical nanomaterials for imaging-guided cancer therapy. Nanoscale 4:6135-6149.

14-Initiative N. N. 2011. What is nanotechnology? National Nanotechnology Initiative website.

15-Karagkiozaki V., Logothetidis S. and Pappa A.-M. (2015) Nanomedicine for atherosclerosis: molecular imaging and treatment. Journal of biomedical nanotechnology 11:191-210.

16-Kumar R., Shin W. S., Sunwoo K., Kim W. Y., Koo S., Bhuniya S. and Kim J. S. (2015) Small conjugate-based theranostic agents: an encouraging approach for cancer therapy. Chemical Society Reviews 44:6670-6683.

17- Lee J. E., Lee N., Kim T., Kim J. and Hyeon T. (2011) Multifunctional mesoporous silica nanocomposite nanoparticles for theranostic applications. Accounts of chemical research 44:893-902.

18-Lee J. M., Moon J. Y., Kim T. H., Lee S. W., Ahrberg C. D. and Chung B. G. (2018) Conductive hydrogel/nanowire micropattern-based sensor for neural stem cell differentiation. Sensors and Actuators B: Chemical 258:1042-1050.

19-Lin P., Moore D. and Allhoff F. 2009. What is nanotechnology and why does it matter?: from science to ethics. John Wiley & Sons.

20- Manzano M. and Vallet Regí M. (2020) Mesoporous silica nanoparticles for drug delivery. Advanced functional materials 30:1902634.

21-Matsumura Y. (2008) Polymeric micellar delivery systems in oncology. Japanese journal of clinical oncology 38:793-802.

22-Mokhtarzadeh A., Tabarzad M., Ranjbari J., de la Guardia M., Hejazi M. and Ramezani M. (2016) Aptamers as smart ligands for nano-carriers targeting. TrAC Trends in Analytical Chemistry 82:316-327.

23-Nikoleli G.-P., Siontorou C. G., Nikolelis D. P., Bratakou S., Karapetis S. and Tzamtzis N. (2018) Biosensors based on microfluidic devices lab-on-a-chip and microfluidic technology. Nanotechnology and biosensors:375-394.

24-Noah N. M. and Ndangili P. M. (2019) Current trends of nanobiosensors for point-of-care diagnostics. Journal of Analytical Methods in Chemistry 2019.

25-Northfelt D. W., Martin F. J., Working P., Volberding P. A., Russell J., Newman M., Amantea M. A. and Kaplan L. D. (1996) Doxorubicin encapsulated in liposomes containing surface bound polyethylene glycol: pharmacokinetics, tumor localization, and safety in patients with AIDS related Kaposi's sarcoma. The Journal of Clinical Pharmacology 36:55-63.
26-Rangasamy M. (2011) Nano technology: a review. Journal of applied pharmaceutical science 1:8-16.
27-Sakamoto J., Godin B., Hu Y., Blanco E., van de Ven A. L., Vellaichamy A., Murphy M. B., La Francesca S., Schuenemeyer T. and Given B. (2013) Nanotechnology toward advancing personalized medicine. 2013) Handbook of Personalized Medicine. CRC Press, Boca Raton:1-714.
28-Schiffman J. D., Fisher P. G. and Gibbs P. (2015) Early detection of cancer: past, present, and future. American Society of Clinical Oncology Educational Book 35:57-65.
29-Torchilin V. P. (2007) Targeted pharmaceutical nanocarriers for cancer therapy and imaging. The AAPS journal 9:E128-E147.
30-Veiseh O., Tang B. C., Whitehead K. A., Anderson D. G. and Langer R. (2015) Managing diabetes with nanomedicine: challenges and opportunities. Nature Reviews Drug Discovery 14:45-57.
31- Wu X., Yang H., Yang W., Chen X., Gao J., Gong X., Wang H., Duan Y., Wei D. and Chang J. (2019) Nanoparticle-based diagnostic and therapeutic systems for brain tumors. Journal of Materials Chemistry B 7:4734-4750.
32-Yadid M., Feiner R. and Dvir T. (2019) Gold nanoparticle-integrated scaffolds for tissue engineering and regenerative medicine. Nano letters 19:2198-2206.
33-Yang D. (2021) Application of nanotechnology in the COVID-19 pandemic. International journal of nanomedicine 16:623.
34-Zhang H., Xia J., Pang X., Zhao M., Wang B., Yang L., Wan H., Wu J. and Fu S. (2017) Magnetic nanoparticle-loaded electrospun polymeric nanofibers for tissue engineering. Materials Science and Engineering: C 73:537-543.