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ijirset@gmail.com

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Biomedical Nanotechnology for Health Wellness

¹Deepmala Meena, ²Ram Bilas Meena, ³Harish Kumar Sublania

^{1,3}Assistant Professor, Dept. of Physics, Government College, Kota, India

²Assistant Professor, Dept. of Chemistry, Government College, Kota, India

ABSTRACT: Biomedical nanotechnology is dedicated to exploring nanoscience and nanotechnology for health wellness, with the ultimate goal of personalized health management. Reports released by health agencies have confirmed the significant role technologies play in disease monitoring, treatment, and progression management. It is also evident that the introduction of nanotechnology assisted approaches makes diagnostics and treatment of a targeted disease more sensitive, affordable, and accessible. The tunable performance of nano-systems, investigated for biomedical research, is advantageous for the design and development of therapies that consider patient profiles i.e., personalized health management. Besides salient features of nano-assisted approaches, the introduction of numerical approaches i.e., artificial intelligence (AI), involving deep & machine learning, and bioinformatics has emerged as a very useful tool in understanding predictions and trends. Such information is useful to understand epidemic variations, therapy optimization, and risk assessment. At the same time, suitable management of bioinformatics is crucial for a timely and effective analysis. Presently, significant efforts are being made to promote the internet of medical things (IoMT), an approach in biomedical nanotechnology for data sharing, storage, and analysis. IoMT outcomes are useful in transitioning biomedical technology from the laboratory to the field. Keeping these outcomes in mind, efforts are being made to transform electronic health to intelligent health.

KEYWORDS: nanotechnology, biomedical, diagnostics, health, therapy, laboratory, patient, profile

I. INTRODUCTION

In 2000 the United States launched the National Nanotechnology Initiative and, along with it, a well-defined set of goals for nanomedicine.[1,2] This Perspective looks back at the progress made toward those goals, within the context of the changing landscape in biomedicine that has occurred over the past 15 years, and considers advances that are likely to occur during the next decade. In particular, nanotechnologies for health-related genomics and single-cell biology, inorganic and organic nanoparticles for biomedicine, and wearable nanotechnologies for wellness monitoring. When rowing a boat across a big lake, you can paddle for a long time, and the far shore will continue to appear almost as far away as when you started. However, when you look back to your starting point, the amount of distance traveled can be startling. In 2000, Neal Lane, then President Clinton's Science Advisor, presented the first Implementation Plan for the US National Nanotechnology Initiative (NNI). That document laid out some clear goals for nanomedicine:

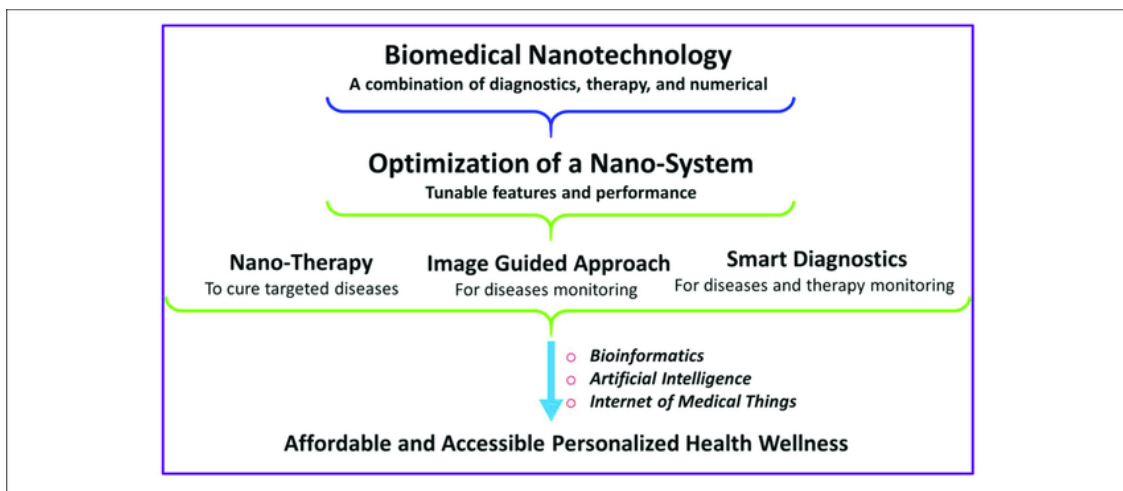
- i) Rapid, more efficient genome sequencing enabling a revolution in diagnostics and therapeutics
- ii) Effective and less expensive health care using remote and in vivo devices
- iii) New formulations and routes for drug delivery that enormously broaden their therapeutic potential by targeting the delivery of new types of medicine to previously inaccessible sites in the body
- iv) More durable rejection-resistant artificial tissues and organs
- v) Devices that enable vision and hearing aids
- vi) Sensor systems that detect emerging disease in the body, which ultimately will shift the focus of patient care from disease treatment to early detection and prevention.

The goals of the 2000 NNI have largely stood the test of time and even capture some of today's grand challenges in the health sciences. I'll look back at selected items from this list and provide brief descriptions of how far we have come. For most of these goals, nanotechnologies have played supporting, albeit gradually increasing, roles. For example, any discussion of diagnostics, early disease detection, and disease prevention would likely lead with the amazing progress



in the “-omics” fields and the emerging efforts to define “wellness” quantitatively that ultimately will provide the baseline against which disease is measured. However, a little digging reveals that nanotech is playing increasingly important roles in the emerging generation of omics tools. For other goals, such as those associated with new formulations and routes for drug delivery, nanotech has played a major role, even if widespread clinical applications are still on the horizon. Just like the rower’s view from the lake, the various end goals of the NNI are still a ways off, but the distance covered is impressive.[3,4]

Although the goals of the 2000 NNI still appear prescient, there have been major breakthroughs in medicine and biotechnology that weren’t anticipated 15 y ago. For example, single-cell biology was not really a field in 2000, but now it is one of the most rapidly evolving assay biotechnologies, with potentially disruptive implications in terms of how we think about biological systems and how we understand human disease and health states. As a second example, until a couple of years ago the idea of harnessing a patient’s immune system as a powerful anticancer drug was more or less a backwater of cancer research. Immune checkpoint inhibitors, which now are dominating new cancer clinical trials, with several recent Food and Drug Administration approvals, were only being identified in 2000. However, cancer immunotherapy (4) in the forms of both checkpoint inhibitors and cell-based therapies is increasingly altering the dialogue of “cancer treatments” to “cancer cures.” These two breakthrough areas relate somewhat to the Year 2000 NNI goals 1 and 3, respectively, although the supporting roles that nanotech is playing in the development of these new fields are quite distinct from those anticipated 15 y ago.[5,6]



II. DISCUSSION

Nanotechnology — the science of the extremely small — holds enormous potential for healthcare, from delivering drugs more effectively, diagnosing diseases more rapidly and sensitively, and delivering vaccines via aerosols and patches. Nanotechnology is the science of materials at the molecular or subatomic level. It involves manipulation of particles smaller than 100 nanometres (one nanometre is one-billionth of a metre) and the technology involves developing materials or devices within that size — invisible to the human eye and often many hundred times thinner than the width of human hair. The physics and chemistry of materials are radically different when reduced to the nanoscale; they have different strengths, conductivity and reactivity, and exploiting this could revolutionise medicine. For example, a major challenge of modern medicine is that the body doesn’t absorb the entire drug dose given to a patient. Using nanotechnology, scientists can ensure drugs are delivered to specific areas in the body with greater precision, and the drugs can be formulated so that the active ingredient better permeates cell membranes, reducing the required dose[7,8].

Rich countries are investing heavily in nanotechnology for health. The first generation of cancer drugs delivered via nanoparticles, for example, has already been approved by the US Food and Drug Administration (FDA). However, it is still early days for nanotechnology in healthcare and whether it will be of value to resource-poor countries is still hotly debated. Critics argue that when millions of people in countries like India or those in Sub-Saharan Africa are dying because of a lack of access to even basic healthcare, investing in cutting-edge technologies is a ludicrous waste of money.[9,10] And experts are concerned that the toxicity of nanoparticles to human health and the environment has not been studied extensively enough. For instance, a 2004 report by the UK Royal Society and Royal Academy of



Engineering recommended that nanoparticles and nanotubes — cylindrical carbon molecules that are better conductors than normal carbon molecules — be treated as hazardous waste. Many emerging economies such as Brazil, China, India, Iran, Malaysia, Mexico, Singapore and South Africa have ambitious research and development (R&D) plans for nanotechnology.[11,12] Their governments need to balance short-term health needs with long-term technological investment. Yet while poor countries have an ongoing responsibility to strengthen healthcare systems and provide wider access to medicine, nanotechnology could, in the long run, save lives by making diagnosis and treatment far more effective. A group of scientists who have mapped out the uses of nanotechnology and the needs of global health argue that nanomedicine is relevant for the developing world. They surveyed researchers worldwide and concluded that nanotechnology could greatly contribute to meeting the Millennium Development Goals for health. Specifically, the goals to reduce child mortality, improve maternal mortality and combat HIV/AIDS, malaria and other diseases. [13,14]

Carbon nanotubes, and other nanoparticles such as nanowires, have been used as biosensors to detect diseases such as HIV and cancer. Cancer biosensors can be made, for instance, by attaching nucleic acid probes to the ends of nanowires. These probes are specifically designed to bond to biomarkers that indicate cancer such as mutated RNA. When mutated RNA in a sample interacts with the probes, electric currents are induced along the nanowire, which is detected by the silicon chip in which the biosensor is embedded. [15]

Nanotechnology could also revolutionise drug delivery by overcoming challenges such as how to sustain the release of drugs in the body and improving bioavailability — the amount of active ingredient per dose. Some drugs can now be delivered through ‘nanovehicles’. For example liposomes, which can deliver the drug payload by fusing with cell membranes, have been used to encapsulate HIV drugs such as stavudine and zidovudine in vehicles ranging from 120 to 200 nanometres in size. Since both these drugs have short half-lives, the liposome coating could potentially make them active for longer periods.

Other nanodrug delivery systems include using fullerene ‘buckyball’ cages, [8] and branched nanomolecules called dendrimers [16,17]

Disease diagnosis and screening

- Nanolitre systems (known as lab-on-a-chip): devices that automate a biological process using fluids at the nanolitre scale.
- Quantum dots: nanosized semiconductors that can be used as biosensors to find disease. Because they fluoresce they can be used to tag diseased cells.
- Magnetic nanoparticles: used as nanosensors
- Nanosensor arrays: grids of carbon nanotubes
- Antibody-dendrimer conjugates: branched nanomolecules with antibodies on their ends for diagnosis of HIV and cancer
- Carbon nanotubes and flatter, thin wires called nanobelts or nanowires (often made of gold) as nanosensors for disease diagnosis as they bond to biomarkers that indicate cancer such as mutated RNA
- Nanoparticles as medical image enhancers: medical imaging relies on looking for contrasts in the way light is scattered in healthy tissue compared with diseased tissue. The sharper this contrast, the more accurate the diagnosis. Nanoparticles are able to give medical imaging techniques a sharper resolution, making it easier to identify disease.

Drug delivery systems

The choice of system depends on the way they bind with the drug and the type of drug treatment.

- Nanocapsules: these are pods that encapsulate drugs, which ensures the drugs are released more slowly and steadily in the body



- Liposomes: artificial vesicles made up of a lipid bilayer so they can fuse with and penetrate membranes easily. These have been used to treat diseases such as cancer, fungal infections, hepatitis A, and influenza.
- Dendrimers: tree-shaped synthetic nanomolecules that carry drugs in the tips of the branches.
- Buckyballs: spherical nanoparticles can carry more than one drug at a time. They are useful in the treatment of diseases such as cancer and other diseases where monotherapy can lead to drug resistance
- Nanobiomagnets which carry drugs, for cancer for instance, into the body and are held at the target site by an external magnet. The purpose of this is to concentrate the drug at the tumour site for long enough for it to be absorbed.
- Attapulgitic clays with nanometre-sized pores that are ideal for filtering out harmful bacteria from water
- Nanotechnology can also provide alternatives to injectable vaccines if the inactive virus is bound up with nanoparticles to increase the immune response.

Health monitoring

Nanotubes and nanoparticles can be used as glucose, carbon dioxide and cholesterol sensors and for in-situ monitoring of homeostasis, the process by which the body maintains metabolic equilibrium. In the developed world, cancer is top of the list of diseases being targeted for nanomedical treatment (see panel 2 on cancer). Cancer prevalence is rising fast in the developing world with 70 per cent of all cancer deaths, according to WHO. In developing nations, the use of nanotechnology is also being explored in the fight against infectious diseases such as HIV and TB. [18,19]

Nanotechnology advances have been heavily focused on cancer, mainly on diagnosis and drug delivery. Drugs carried by polymer-coated nanoparticles have been used to treat multidrug-resistant breast and ovarian cancer with the chemotherapies paclitaxel, which inhibits cell division, and lonidamine, which suppresses energy metabolism in cancer cells. The nanoparticles are designed to target an epidermal growth factor receptor, which is overexpressed in tumour cells. Detecting cancer early can make a significant difference to the survival rate. Using magnetic nanoparticles in a miniature magnetic resonance sensor is so sensitive, scientists can detect as few as two cancer cells in one microlitre of a biosample, radically increasing early detection. Scientists at Stanford University in the United States have used nanotechnology to devise a highly specific method of killing cancerous cells. They inserted carbon nanotubes into cancer cells and then exposed the tissue to near-infrared laser light, heating up the nanotubes and killing the cancer cells while leaving the healthy cells intact. [20,21]

The Central Scientific Instruments Organisation of India has designed a nanotechnology-based TB diagnostic kit, currently undergoing clinical trials. This would cut both the cost and time required for TB tests, and also require a smaller amount of blood for testing.

Nanotechnology is also being used to treat TB more effectively. Existing TB treatment requires a complex drug regimen delivered over a period of months. Many patients don't take the drugs properly or fail to complete the course. Drug formulations based on nanotechnology degrade more slowly, allowing more of the active ingredient to be delivered so that fewer doses are required. The drugs are encapsulated in biodegradable polymers such as liposomes and microspheres, which ensure sustained delivery of the medicine. Nanoparticles of polylactide co-glycolide, a polymer often used to deliver drugs since it degrades well and doesn't cause an immune reaction, have been successfully tested as drug carriers for TB by groups at US-based Harvard University, the Postgraduate Institute of Medical Education and Research in India and the Council for Scientific and Industrial Research in South Africa. Nanoparticles could also be the basis for delivering an aerosol TB vaccine. Needle-free, and therefore not requiring trained personnel to administer it, the vaccine is stable at room temperatures — important in rural areas that lack a reliable cold chain. [22]

Vaccines

Nanotechnology could herald a new era in immunisation by providing alternatives to injectable vaccines for diseases that affect the poor. Injectable vaccines need to be administered by healthcare professionals, who may be scarce in developing countries, particularly in rural areas. Vaccines also need reliable refrigeration along the delivery chain.



Scientists are working on an aerosol TB vaccine . They are also investigating a nanotechnology-based skin patch against West Nile Virus and Chikungunya virus.

III. RESULTS

Nanotechnology has been widely used in our daily life based on techniques in a micro sense at the nano-level. With the developing of nanotechnology, plenty of nanomaterials have been synthesized and industrially manufactured for different applications. Following the creation of novel nanomaterials, advanced nanotechnology also includes instrumental analysis, biochemical assays, process engineering, quality assurance (i.e., stability and bioequiavailability), in vivo and in vitro studies, statistical investigations (including AI algorithms), ethical and social aspects. Biomedical and healthcare applications are key areas in the field of advanced nanotechnology. Typical biomedical works involve genetic engineering, cell engineering, fermentation engineering, enzyme engineering, biochip technology, pharmaceutical materials, gene sequencing technology, tissue engineering technology, biological information technology, and so forth.[19,20]

With the said techniques, many nanomaterials-based products have been developed, including biomedical materials and products, artificial organs, medical imaging and diagnostic equipment, medical electronic instruments and monitoring devices, modern medical treatment equipment, medical information technology, rehabilitation engineering technology and devices, tissue engineering, etc. [21] Typical healthcare works involve human environment study, living environment and health, food and health, occupational environment and health, social environment and health, health statistics overview, statistical studies, etiology and etiological inference, disease distribution, epidemiological research methods, disease prevention and control, public health emergencies and emergency treatment.

IV. CONCLUSIONS

The ability to investigate substances at the molecular level has boosted the search for materials with outstanding properties for use in medicine. The application of these novel materials has generated the new research field of nanobiotechnology, which plays a central role in disease diagnosis, drug design and delivery, and implants. There is use of metallic and metal oxide nanoparticles, carbon-nanotubes, liposomes, and nanopatterned flat surfaces for specific biomedical applications. The chemical and physical properties of the surface of these materials allow their use in diagnosis, biosensing and bioimaging devices, drug delivery systems, and bone substitute implants. The toxicology of these particles is also discussed in the light of a new field referred to as nanotoxicology that studies the surface effects emerging from nanostructured materials.[22]

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