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Nanotechnology for Medical Physicists: Principles and Future Prospects

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Annotation: Nanotechnology has emerged as one of the most promising scientific and technological developments in the twenty-first century. Following the discovery of novel phenomena on nanometer scales, and the development of new methods and techniques capable of fabricating and characterizing matter at the nanometer-sized scale, an explosion of interest in this new realm of science and technology has reinvigorated traditional areas of knowledge and methodologies. Nanotechnology is currently being employed in a vast array of disciplines, and is expected to influence the ways in which we live, work, and interact with the world around us.

The future of nanotechnology applications received a shot in the arm with signed contract in January 2003, in the White

House, Washington, between the National Nanotechnology Initiative, representing the Department of Energy, Department of Commerce/National Institute of Standards and Technology, National Science Foundation, and Department of Defense, and the Environmental Protection Agency. This monumental contract outlined that the Federal Government would channel up to one billion dollars over the coming years into studying the environmental, health and safety implications of nanotechnology, thus indicating that nanotechnology had truly arrived . Moreover, the contract initiated without delay the requirements for immediate strategic action by both public and private sectors to protect health, safety, and the environment.

1. Introduction to Nanotechnology

Nanotechnology is considered a scientific phenomenon that has evolved over many years, although it has recently gained a lot of attention worldwide. The term "nano" is used as a unit prefix in the metric system, representing a billionth (10^-9). One nanometer is a millionth of a millimeter, or about 1/80,000 of the diameter of a human hair [1]. Nanotechnology was initially conceived as a theoretical concept, however it has since transitioned into a practical application. The basis of nanotechnology lies in the manipulation of matter on an atomic and molecular scale to create new and unique structures with size-dependent properties. Such properties sometimes are markedly different from those on a macroscale or from individual atoms or molecules. The field has become interdisciplinary in nature, and has attained maturity by adopting materials and devices with critical dimensions in nanometric clusters [2]. These materials can be classified as three types: nanoparticles, nanofibers, and nanofilms. This has lead to the development of a promising technology with high impacts in different domains, making major advances in pharmacology and medicine. The full understanding and potential of this technology should be explored by professionals in health sciences and associated areas working in hospital services and the academia. There are three main goals of this essay: first, to provide detailed insight into this blossoming technology; second, to explore potential applications in medicinal sciences; and third, to examine the future prospects for this technology. [3][4]

1.1. Definition and Scope of Nanotechnology

Nanotechnology was first defined in the year 1974 as the detailed design, sophisticated characterization, production, and diverse applications of intricate structures, innovative devices, and complex systems by precisely controlling their shape and size at a very small, specific scale known as the nanometer scale level. The term "nano" refers to one billionth of a meter, or specifically one part of ten to the power of negative nine meters. For the purposes of scientific research here and now, nanotechnology is currently defined as the systematic design and comprehensive production of structures, specialized devices, and advanced systems that possess one or more crucial processes involving entire materials, all of which have dimensions that fall within the extremely small range of 1 to 100 nanometers. This field not only plays a pivotal role in various scientific disciplines but also has the potential to transform numerous industries by introducing remarkable innovations and breakthroughs. [5][2]

The focus of nanotechnology is materials and devices (system) at that scale level, and such a material has a unique physical, chemical, biological property, and biological activity because of its size. Nanotechnology is an interdisciplinary science in physics, chemistry, biology, material technique, and engineering studies with the interdisciplinary process at the sound construction, atomic levels, and the synthesis of new materials (nano system with a better designed and higher performance). Nanotechnology involves imaging, measurement, techniques, and manipulation, and fabricating, treatment, at a single atom or molecules level. Nano-structured materials are the focus of 90% of the current researches and 89% of the applications, and design alters because different bulk materials of the same composition have a size-dependent structure. At the same time, nano-structured composite materials became greater in size. The primary use of these is the bridge between bulk materials and thin films, and new pharmaceutical, catalysts, electronic materials as well as other microelectronic components, resulting in design, and potential to produce a tenfold decrease in cost and energy 1000-fold increase in that power or function. 21 sections have been formed or have over 100 experts currently investigating site opportunities and risks in the sustained development of nanotechnology using in Korea. [6][7][8]

Literature Review

2. Fundamental Principles of Nanotechnology

Nanotechnology is the design, characterization, production, and application of structures, devices, and systems by controlling shape and size at the nanometer scale level. The nanometer scale is a length scale at which properties of materials differ appreciably from those at a larger scale. The principles of quantum mechanics are fundamental in understanding and designing the interactions of materials with structures at the nanoscale level, and in the application of the materials or structures. Hence, a brief introduction of the fundamental principles that underpin nano-technology is provided. This is followed by some nano-structures and the potential of each of the principles of application. The aim is to bridge theoretical knowledge with practical implications. It is important to realize that people have manipulated nanomaterials and created nano-structures and have noted important effects for centuries, although the effect of interest was not always of direct interest. There are myriad reasons why altered properties are seen at such scales. These are but a few of the more obvious. The text is organized as a discussion to focus on three key: phenomena, the quantum effect of structure size ie: quantum confinement, the significant increase in surface area to volume ratio as particle size is greatly reduced leading to unusual: surface effects, and the finite size effect of especially particles ie: a length scale dependent property such as strength or reactivity. It will conclude with a significantly extended appendix of these phenomena (over 30 pages) updating current knowledge regarding the materials or micro/nano-structures where these effects arise and/or are poorly understood, and those technologies where study of or exploitation of these phenomena will likely become increasingly significant to provide a stimulating basis for development [5]. [9][10][11][12]

2.1. Quantum Mechanics and Nanoscale Phenomena

Medical physics primarily concerns the application of physical principles in the diagnosis and treatment of diseases by medical means. The upsurge and adoption of modern technology such as nanotechnology provide an innovative direction for new research avenues. Nanotechnology deals with materials, devices, and other structures with at least one dimension sized from 1 to 100 nm. The materials at the scale of nanoparticles typically exhibit different properties than their bulk counterparts, owing to atomic and/or molecular behaviors dictated by quantum mechanics. Sections 2.1 and 2.2 focus on introducing quantum mechanics and nanomaterials, respectively, to provide a fuller perspective. [12]

In the year of 1900, Max Planck proposed the idea that the energy of light is quantized, leading to the Planck radiation law. A few years later, Albert Einstein showed an explanation for the photoelectric effect based on the same idea. The early 20th century saw several other important experimental signatures of quantum physics, such as the black-body radiation, the atomic spectra, and the peculiar behavior of particles in the novel regime of atomic sizes [13]. Nonetheless, there was no fundamental understanding of these disparate phenomena at the time. With the development of quantum mechanics in the mid-1920s, Wolfgang Pauli, Werner Heisenberg, Erwin Schrödinger, and others formulated the various phenomena into a consistent theory. From it, arose additional paradoxes manifesting in dramatic and profound fundamental issues, like the idea of wave-particle duality, the concept of electron tunneling, and the quixotic prospect of quantum superposition. With time, however, it was elucidated how these oddities arise from the postulates and equations of the concepts—so odd in the realm of everyday life, but whose predictions have been confirmed to astonishing accuracy in countless experiments ever since. Of a more sophisticated nature and significance are the more practical and far-reaching consequences of quantum behavior at the microscopic level, why gases and solids behave differently, and the limitations of classical physics in explaining and predicting things in the quantum domain. It is the development and explicit understanding of these issues that has enabled the design and fabrication of the myriad technologies that so pervade modern life, from the internet to personalized medicine. Looking broadly, many current and upcoming novel technologies—including, for example, the exponentially-expanding industry of novel, scalable, and benign pharmaceutics to supplant traditional chemical medicines—cannot be accounted for without a thorough understanding of the quantum properties of materials and devices. [14][15][16][17]

Materials and Methods

3. Nanomaterials in Medicine

Advancements in nanotechnology have remarkably stimulated extensive interdisciplinary research collaboration among medical physicists, engineers, and clinical practitioners, culminating in a myriad of innovative medical applications that are being actively translated from groundbreaking discovery to viable commercialization. An estimated 4000 distinct medical products pertaining to nanotechnology have now been successfully produced and are currently available on the market, while more than 100 pioneering nanomedical products have reached advanced stages in clinical trials. On average, a remarkable 600 new nanomedical products are added to the development pipeline every single year, significantly increasing not only the speed but also the exponential growth of new research findings and technology innovations within this crucial field. [1] [18][19][20]

Many types of nanomaterials have been synthesized, each of which is normally named based on the primary composition to include nanoparticles or nanowires, such as nanotubes, nanorods, nanofibres, and nanowhiskers, etc. Due to rapid improvements in fabrication technology, new polymer materials, composed of assembled nanofibers, nanowires, and nanoplates, have recently become available and are beginning to be used for new product applications. Since the physical dimensions of nanomaterials are less than the size of cells, their application within the human body can foster new dynamics by directly influencing the biochemical interactions at cellular and subcellular levels. In particular, the possibilities to increase the surface area and tailor the specific physiological, pathological, and pharmacological surface characteristics, provide underpinnings for the increased use of nanomaterials for medical applications, enhancing products' performance with biological and mechanical properties tailored specific to the intended clinical use. Given the unique characteristics and excellent potential, nanomaterials are currently of great interest in medicine, presenting a large range of applications in the controlled release of drugs, contrast agents for diagnosis, and coatings for implants as well as instruments and tools in surgery. On the other hand, the unique potential to functionalize the chemical properties at the molecular level allows nanomaterials to be employed as nanoscale molecular supports for target-specific drug delivery and imaging agents. Based on this foundation, medical experts can expect that many products will be developed involving nanotechnology advances which harness the preferential accumulation of materials within pathological tissue through stimulus gradients of surface modification, electrical fields, or magnetic fields that can minimize side effects from good tissue; they can achieve on-demand scheduling with long circulating macromolecular drug delivery systems, or sustained release properties; also, the high yield fabrication of biopolymers in nanoparticle form at the desired particle size and preferably with monodispersity is likely to have an impact on medical products. At the same time, research and development of competitive technologies for the fabrication of nanomaterials in a controlled manner is greatly expanding aiming for broad clinical applications such as tailored cellular uptake, programmed release kinetics, bioactivity, and degradation rates. [21][22][23][24][25][26][12][27][28]

3.1. Types of Nanomaterials

Nanomaterials have garnered a significant amount of interest and attention in recent years, and this growing fascination can be largely attributed to the unique and variable properties that stem from the specific structural and compositional features of each material at the nanometer scale. These fascinating nanomaterials can take on a diverse range of distinct forms, which include, but are not limited to, nanoparticles, nanowires, nanorods, nanoshells, nanotubes, and quantum dots. In addition, there are structured composites that may involve a combination of molecules and/or various polymers. Because of these numerous and intriguing reasons, the development of innovative nanotechnologies has made remarkable strides, and thus nanomaterials are frequently applied across various sectors, especially within the medical and health-related fields, where they demonstrate great promise and effectiveness in selective applications. A number of researchers with a keen interest in utilizing nanomaterials to propel forward the research in this dynamic field may find themselves largely unaware of the exact nature and characteristics of nanomaterials. Therefore, the paragraph aims to provide a clear overview of the types of nanomaterials that are most frequently applied in medical and health-related applications. Rather than exhaustively detailing every single material available, this text divides the topic of nanomaterials into a few exemplary categories that embody the essence of their utility. The majority of medical and health-related applications predominantly focus on various types of nanomaterials, specifically metal-based nanoparticles, polymeric nanoparticles, and carbon nanomaterials, which include nanotubes, fullerenes, and the highly regarded graphene. Furthermore, nanoparticles that take the form of nanodots, dendrimers, micelles, liposomes, and even quantum dots are often included in discussions centered around their important role as delivery carriers. The reason for this prominence lies in their size and shape adaptability along with their high surface area, which allows for enhanced interactions. Nanomaterials are fundamentally composed of unique materials that possess varied structural properties at the nanoscale. Broadly categorizing these materials, metallic, polymeric, carbon-based, silica, and lipid-based components emerge as the most widely utilized materials in the domain of nanotechnology. Each of these individual materials can exhibit variable physical and chemical properties owing to factors such as the structure they embody, the inherent composition, and the methods employed during preparation. Additionally, composite materials or elements may be strategically combined with specific materials to enhance the resultant nanoparticles' characteristics further. Due to these diverse properties, differently prepared nanoparticles ultimately lead to disparate interactions with bio-samples, and as a consequence, their performance in terms of diagnostic, therapeutic, and therapeutic monitoring capabilities varies significantly. [29][30] [31][32][33][34]

Results and Discussion

4. Applications of Nanotechnology in Medicine

This is an exciting time to be involved in medicine as practitioners see outstanding improvements in patient care due to scientific advancement. Nanotechnology is one of the newest scientific disciplines and it promises a transformation in healthcare practices at a truly global level. This is evident from the spending on nanotechnologies, including investments in the aggregation and use of nanotechnologies and an increasing number of private sector companies. The potential for nanotechnologies to grow is evidenced by the total value of nanotechnologies currently on the market which is expected to increase significantly over the next decade. This text will aim to provide readers with a starting point to the field of nanotechnology and its implications for those who are practicing in a clinical environment. [35][36]

The field of nanotechnology has wide and varied applications in medicine, which importantly includes the development of drug delivery systems which enables the precise timing and delivery of the right amount of the drug to the right location. This in turn limits both the side effects and maximises the drug's effectiveness in therapeutics. There are also a range of other applications including the development of nano chaotic solutions for imaging, the development of diagnostic techniques and even the treatment for cancer. A centrifugation technique has been developed which aligns gold nan-shells on cancer cells and then by firing an infrared bard of short laser light at the cell. The temperature of the nan-shells can be made to rise, leading to the death of the cancer cell. This would result in a significant advance compared to conventional treatment for cancer. [37][38]

4.1. Drug Delivery Systems

Medicinal physicists, as experts who are usually engaged in quantitative research of biological and physical aspects of radioactive therapy and medical imagery, are also key members of multidisciplinary research teams. In this context, a wide knowledge of nanotechnology fundamentals and advancements can be beneficial to comprehend the applications and restrictions of nanotechnology in medicine. Given their background and interdisciplinary expertise, medicinal physicists are in an outstanding position to study how nanotechnology might affect their respective fields and to explore the prospects of making adept contributions. Measurement of nanoscale materials size and counting of particles are amongst the most important methodologies required for the regulation of nanotechnology. As such, they are essential to study the effectiveness and toxicity of nanoparticles. What nanometer-thick materials are, how their properties are altered by changing their dimensions, and how they can be fabricated are basic queries that physicians require to delve into nanotechnology's possible predispositions to the field of medicine. Principles such as the physical and chemical attributes of nanomaterials suggest that the manipulation of particles down to the nanometer scale can produce an extensive diversity of particles with various qualities that are undetectable in bulk materials. With the development of innovative techniques and a radical rise in scientific interest in nanotechnology over recent years, extensive study has been executed. From an interdisciplinary approach, recent development in nanotechnology and its utilization in medicine are outlined and probable patterns in future research are considered. Further, critical experimental work involves a study of the toxicity and biological repercussions of nanoparticles intended for usage in medicine with the use of radiation. [39][40][24]

5. Nanotechnology in Imaging and Diagnostics

Nanotechnology has the potential to impact a variety of different fields including medicine, engineering, computing, electronics, optics, and energy production. In medicine, this broad and burgeoning field holds significant promise for revolutionizing multiple disciplines, including tissue engineering, drug delivery, imaging, diagnostics, surgery, and cancer treatment. This text aims to demystify complex introductions of nano-biology in biomedical literature for medical physicists, delineating underlying nanotechnologies and elucidating contemporary and futuristic applications in medicine. The Review cuts the broad panorama of nanobiological applications to nanotechnology in chemotherapy, radiotherapy, as well as in imaging and diagnostics. Going further, more sophisticated nanoparticles and their modern direction in nano biomedicine will be reviewed. By reading up on the discipline's history and some of the challenges being tackled, the trepidations of earlier years can be set aside [29]. Cut clearer, more illuminating through the twilight's glare, the course can be set by briefly explaining the fears of the brave new world the medical physicists are on the verge of entering. After this short prologue many fears and misconceptions will fade away, quantum by quantum. Clearly, tremendous scientific and economic resources are today being poured into the field of nanotechnology. The average budget of the National Nanotechnology Initiative in the USA is above one billion dollars per year. Far greater than the impoverished total budgets of most other nations, the financial arms race over nano- and biotechnology is being won by hegemonic powers. Subsequently, the potential benefits of nanotechnology are being felt in each corner of COMP, and medical physics departments across the globe find themselves under pressure to fund a nanoguru. One helpful feature of this field are the discrete, albeit wavicle, units in which it is measured—particles no bigger than about one nanometer. [41][32][42]

5.1. Nanoparticles in Imaging

There is a huge potential for using nanoparticles in medical imaging; therefore, there is no doubt they will offer a revolutionary opportunity for imaging in the near future. This section will focus on the application of nanoparticles. These common platforms for medical diagnostic nanoparticles and their unique advantages over traditional imaging agents are discussed in the following sections. There are a variety of nanoparticles available for imaging. For example: gold nanoparticles, quantum dots, silica nanoparticles, and magnetic nanoparticles. Gold nanoparticles are cost effective, easy to fabricate, and have fluorescence quenching properties; however, they may potentially have issues with cytotoxicity. Quantum dots have great light stability, high quantum efficiency, and narrow emission bands, but there are potential toxicity issues. Silica nanoparticles have high surface area to volume ratio and versatile surface functionalization; however, their emission quantum yields are generally low. Magnetic nanoparticles have the advantages of biocompatibility, versatile surface coating, and small particle size. Functionalized with targeting molecular probes on the surface of the nanoparticles, these nanoparticles can potentially offer targeted imaging in specific tissues or cells. The versatility of surface property modification also allows simultaneous loading of targeting molecules, therapeutic agents, and molecular probes. Most notably, magnetic nanoparticles can be used for magnetic-resonance-device and could potentially generate the most meaningful data by allowing the implementation of a good contrast agent. Since tissue structures have natural variations in water content and water molecules are moving in Brownian motion, magnetic field manipulations in the presence of a contrast agent result in image contrast that is dictated by factors other than anatomical composition. Amplifying these intrinsic contrasts involves the use of exogenous contrast agents, which cause neighboring water proton T1 and T2 to shorten. [43][44][45][46]

6. Nanotechnology in Cancer Therapy

Nanotechnology in cancer therapy has the potential to revolutionize treatment strategies, from improved diagnosis and screening to smart targeted therapeutics and novel monitoring devices. This discipline has received substantial attention due to the higher potential of some nanoparticles for accumulation in tumor tissue compared to normal tissues. A wide variety of nanomaterials have been proposed for various approaches on how these can be applied for cancer targeting. In cancer therapy, a crucial aim is to achieve high cancer cell toxicity while minimizing damage to healthy cells, leading to higher therapeutic efficacy and lower side effects. Furthermore, new and innovative therapeutic modalities are under development that are expected to significantly benefit from incorporating nanotechnology. Dramatic advances in multifunctional nanomaterials, such as theranostic nanoparticles, have been achieved in recent years, at an early stage of investigation and clinical trials, and some fascinating works have been outlined and are very likely to introduce ground-breaking approaches in the next few years. [47][48][46]

Significant research effort has been directed at improving the possibilities to facilitate the translation of the achievements, from the research of this exciting field, to the clinical practice. Nanotechnology is progressively changing the prospects of cancer therapy. This is being illustrated by escalating preclinical and clinical studies, as well as the fast growth of nanotherapeutics tested for cancer treatment in humans. In spite of the noticeable progress of nanotechnologic developments for cancer treatment applications, there are also difficulties and drawbacks that have to be faced. Efforts should be made beyond the scientific community to further promote a worthwhile blending of knowledge. Such collaborations along with additional research attempts could make this powerful scientific technology the fundamental component in designing the curative potential of oncologic treatments. [47][49][48][50]

There is a hope, therefore, that these approaches will lead toward pioneering further successful and extensive nanotherapeutic applications in clinical oncology. Nonetheless, an adequate selected scientific knowledge should be timely established across the community. [51]

6.1. Hyperthermia and Photothermal Therapy

1) Cancer represents one of the major therapeutic challenges in the present time and kills millions of people each year. Common cancer treatments, such as radiation therapy and chemotherapy, have many side effects because of the low selectivity for killing cancerous rather than healthy cells and tissues. Thus, improving the selectivity of these treatments through minimally invasive techniques is needed. Nanotechnology may offer the possibility of more efficient and target-specific forms of cancer therapy. Using nanoparticles to absorb light and converting it into heat is the principle basis of photothermal therapy (PTT) and is known for its high degree of selectivity in destroying cancer cells while leaving healthy tissue intact. This review mainly focuses on such applications and how these approaches can be best exploited. In addition, hyperthermia, another major therapy based on nanoparticle platforms, was used and discussed. Nanotechnology allows a range of materials being used as nanoparticles for therapy such as gold, silver, carbon-based nanomaterials, superparamagnetic iron oxide, etc. Gold nanoparticles (GNPs) are particularly attractive and reviewed in detail driving the main focus of the application of these materials to current ancillary treatments in clinics and represents a rapidly growing field [52]. The review provides example and status in this area and suggests where future studies can best be directed. [47][49]

7. Nanotoxicology and Safety Considerations

Nanotechnology has the potential of revolutionizing medical technology. Today, the influences of nanoparticles on living organisms in various levels are known as nanotoxicology. The lung is mostly affected by tenacity nanoparticles and causes various changes there. It has been shown that tenacity nanoparticles deposit in tissues since they are exposed to 3,3–6,3% of inhaled ones according to the created size. Nanoparticles (NPs) upon exposure can induce diseases including but not limited to pneumoconiosis, pulmonary fibrosis, emphysema, chronic bronchitis, lung cancer, and inflammation. Recently there is an increase in interest in their adverse effects on pulmonary function based on a number of studies proving pulmonary toxicity of certain NPs. Lately, silver NPs were recommended as a good antiviral and antibacterial bio material and found its way into many devices. Silver NPs are likely to stay permanently in the human body. Since they can pass the biological membranes, especially alveolar and blood–brain barriers, and disseminate to every tissue and accumulate. [53][54][55]

Nanomaterials, particles between 1 and 100 nm mean in at least one diameter version, have been brought into use throughout the past few decades in a large range of applications. However, owing to the perilous bio accumulative and toxic potential of NPs, strict legal limits have already been implemented. A novel sample treatment has successfully been developed that resulted in various biological fluids being rendered compatible with ICP-MS so then the metal content of NPs could be determined. NPs exposures were found to be associated with increased aortic vascular function and elevated fibrinogen levels. These data describe an urgent necessity for the associated risks with NP exposures that take a high stance on emerging economies because NP-based techniques are reaching generic availability. Here, the considerations focus on the majority of widespread and excessive use of TiO_2, SiO_2, and Ag NPs. Vascular activity evidently takes from the core of TiO_2 NPs and Ag NPs on aortas in comparison to understanding probable mechanisms based on metal and different pathophysiology are interpreted [56]. [12][57][58]

7.1. Biocompatibility of Nanomaterials

Manufactured nanomaterials including nanoparticles, nanowires, nanotubes and quantum dots have been emerging in various science and technology fields. They attract an increased attention in applications for drug delivery, diagnostics, cell labelling, bioseparation and dental materials. These applications require that nanomaterials be benign for biological systems [59]. The field of medical application of nanotechnology is known as nanomedicine. Chemically functionalized carbon nanotubes have been shown the potential to specifically target certain cells. To make the diagnostic applications of functionalized nanomaterials more attractive and possible their biocompatibility need to be proven. Biocompatible nanomaterials must interact favorably with biological systems. Promoting these interactions will lead to improved investigations of living systems, including antibiotics, diagnostics, and implants, as well as further development in DNA sequencing and the early detection of incurable diseases. Ultimately, biocompatible nanomaterials are required in order to advance the possibility of nanomedicine as a clinical option [60]. [32][24]

Biocompatible materials are capable of performing beneficial effects in a living organism without producing undesirable effects. The term "biocompatible" was first used in the 1960s to refer to the ability of medical polymers to interact with biology. These medical polymers were defined as biologically acceptable and usable for medical purposes. Biocompatible clothing, devices, containers, and packaging improve the quality of products and help in maintaining human health. As the understanding of biocompatibility evolved a new definition was required to encompass the composition and structure of materials. Generally, the limited and passive cell and tissue responses influence many widespread biological, molecular, and cellular events. Considering the complexity of these events, a broad definition can be established: "Biocompatibility is a desirable capability of the material when used in association with the whole or part of a living system-it performs adequately and beneficially, without eliciting any undesirable local or systemic effect". However, the investigation of physical, chemical, thermomechanical, and geometric properties along with selection of appropriate preparation protocols is required due to the wide range of influencing parameters. The research of biocompatibility is accompanied with assays for the evaluation of bioactivity and/or hysteresis of the experimental systems performed on the cellular, tissue, and organism level. [61][62][63][64]

8. Regulatory and Ethical Issues in Nanomedicine

Nanomedicine is a fast-developing field in which nanotechnology is applied to prevent or treat diseases by controlling molecular and cellular processes. Nanomaterials in diagnostic and therapy devices are expected to make early detection, imaging, and drug delivery more effective. For medical physicists, the essential techniques and principles of nanotechnology and nanomedicine are presented in this chapter. After the introduction of the fundamentals of nanomedicine including its present state, the principles and future prospects of 1) molecular imaging of the structures and functions of healthy and diseased tissues, 2) nanoencapsulation of insoluble drugs with the monolayer or multilayer nano-films onto drug crystals and 3) direct intracellular delivery of the gene drug are described. [65][66]

Reviewing these new technologies, the most promising research issues in which medical physicists can participate are identified. Sublectric exploration devices, novel nano-films and nano-droplets for the vaporization of cancer tissues, and direct targeting of cancer stem cells are introduced as innovative applications of these new technologies. Finally, the role of nanotechnology in the novel cancer therapy approach is discussed. For example, the control release of the gene drug inside the cell with the nanoparticle on the plasma membrane, that is produced by the artificial lipid bilayer clarification with the near-infrared laser pulse into the focus. Vigorously investigating these conspicuous topics, cutting-edge nanotech applications with new ideas for the diagnosis and therapy of cancer is stimulated. [47][67][68]

8.1. Current Regulatory Frameworks

Nanotechnology can bring radical innovation to the fight against neglected tropical diseases, complementing the breakthroughs in larger drug delivery in vaccine developments. Developing world populations could benefit from the therapeutic advances resulting from the scientific advances of the last twenty years, which have led to the understanding of cell and molecular biology, and the unravelling of the human genome. A multidisciplinary environment, fostering convergence of medicine, chemistry, biology, physics, engineering, environmental sciences, public health and social sciences, offers a more holistic approach to tackle parasites, bacteria, fungi and viruses that cause ills imposing severe health and economic burdens on hundreds of millions in tropical and subtropical areas [69].

Exploitation of the most recent scientific sub-nanometre techniques such as electron synchrotron, laser and ion beams, DNA and proteomics technology and controlled drug delivery, by a critical mass of developing and developed world scientists and clinicians, offers the setting for breakthrough maturity of efficient nanotechnology applications. An aggressive dissemination strategy ensures worldwide outreach. This five-year joint-programme to the advantage of developing low middle-income countries workers is expected to substantially benefit to the scientific communities and their economies, enhancing research opportunities within a competitive scenario [70]. At national level, 21 week-long courses stimulate local presence and develop the in-depth knowledge required for the trans-national initiatives performed by the Euro Science Foundation, which promotes scientific research at a European level. The project will also establish the Internet Forum of the Nanotechnology Professionals, a pioneering scientific community for the development of post-graduate networks. [71][72][73]

9. Future Prospects and Emerging Trends in Nanomedicine

Nanomedicine has the potential to revolutionize the field of health care. Since medical physicists have broad knowledge in various fields, they can pioneer innovative approaches and applications in this interdisciplinary domain. In particular, medical physicists possess an excellent background in nanophysics and nanotechnology. With a quantum perspective, medical physicists perform routine calculations at a microscopic level, such as X-ray transport in radiotherapy, and have gained experience in practical nanosized applications. Focused research into medical nanotechnology has accelerated this trend in recent years. In essence, nanomedicine refers to the application of nanotechnology to medicine. [24][74]

Nanomedicine is the burgeoning field, which was first described by . However, it did not gain the attention of academia and industry until . The state of development of nanomedicine lies midway between the two prominent states: fantasy and mature technology. Remarkable progress has emerged, but it remains far from fully developing. Nanomedicine has been applied in a considerable number of realms, such as drug delivery, bioimaging, and theranostics. Moreover, as a revolutionary technology, nanomedicine shows prospects to surpass conventional health care. Perhaps the most fascinating feature of nanomedicine is not in the individual treatment methods themselves, but their synergetic effects. Furthermore, nanoparticles exhibit numerous intrinsic properties that can be exploited as triumphant weapons against pathological conditions ([1]). [75][76]

9.1. Personalized Nanomedicine

There are a multitude of ongoing and potential applications of nanotechnology in medicine that can benefit or be of interest to medical physicists. This chapter aims to cover a selection of key areas or activities, although it is by no means exhaustive. It aims to provide an overview of some key principles, current developments and future prospects. Some topics relevant to medical physicists are addressed in this chapter including personalized nanomedicine, cancer treatment, and radiology. [77][32]

In B.C. 400, Hippocrates, the father of Western medicine, thought that environment should be paid attention to sustain human health. Since individuals may have different responses to the same therapy or treatment, personalized nanomedicine has become a promising frontier of modern healthcare. Tailored therapy based on the patient's individual physical characteristics, diagnosis, and clinical history can enhance treatment efficacy and minimize side effects. In this perspective, several innovative strategies – treatment targeting specific cellular mechanisms and pathways unique to the patient – have been thoroughly discussed. Furthermore, the integration of nanotechnology with genomics and proteomics has shown early promise in devising individually tailored treatment plans and thereby improving treatment outcomes. The recent implementation of such individualized and precise therapies in research and clinical settings illustrates existing promises and future challenges. While big data, including genomics and imaging data, will drive personalized nanomedicine forward, issues remain with privacy. Moreover, personalized medicine will increase the price of drugs and treatments. Policymakers should therefore set boundaries in these respects. The vision of personalized medicine can never be realized without wide interdisciplinary cooperation, generous financial support and internally-established rules and standards. It is of utmost importance for the future of medicine to face the challenge [78]. [79][80][81]

10. Conclusion and Summary

The development of diagnostic methods and treatment modalities in medicine has been continuously progressing. In addition to the improvements that have lead to the modernization of the related technologies, the new structures and properties emerging at the micro and nano scales made possible the transformation of biology and medicine into more modern research areas. The convergence of informative science and medical disciplines led to the creation of new fields such as bio mechanics, bio materials, bio instrumentation and health informatics. This on the one hand miniaturized and on the other hand economically facilitated the clinical treatment and diagnosis systems. One of these revolutionary new sciences is the nanotechnology. The science of designing, synthesis and production of new materials, structures, devices and systems with dimensions at the ultra-micro or nano scale is referred to as nanotechnology. Nanotechnology reveals the creation of multifunctinal new products and opportunities as well as the improvement of already available techniques and products.

Medicine is one of the most significant fields which will be influenced by the novel technological advancements. Since the last two decades, the merging conceptual advances in medicine and nanotechnology created a new transdisciplinary course named nanomedicine. Nanotechnology that deals with the manipulation of the matters at the atomic and molecular scale is the science that stands as the essential part of the new conceptual bases. Nanomedicine introduces the personal medication and treatment process which is specific to each individual based on their specific structural, functional and especially genetic properties as opposed to the conventional treatment approach based on the average physiological and biochemical properties of individuals [2]. A goal of the emerging nanotechnologies in medicine is to gather individually tailored treatments using these well resolved measurements obtained at the single cell level [5].

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