Chapter 1

Introduction

1.1 Cancer and statistics

Cancer is a deadly disease, which is initiated by uncontrolled cell growth in any portion of the body associated with invasion and metastasis. Cancer is a foremost health problem throughout the world owing to significant barriers in diagnosis and prognosis [1]. According to the American Cancer Society, the global cancer burden is anticipated to rise to 21.8 million cases by 2030 [2]. Recent data say that a total of 1 658 370 new cancer cases were diagnosed along with 589 430 cancer deaths in the United States in 2015. According to reports from Global Cancer Control, the American Cancer Society and WHO, ~14 million new cancer cases were diagnosed every year, with ~8 million deaths, in 2012 and predicted to grow up to ~25 million by 2030 [3, 4]. Cancer can affect any part of the body (breast, lung, prostate, skin, liver, kidney, pancreatic, brain, colon, rectum, thyroid, etc) and can readily extend to other healthy parts of the body through the blood circulation and lymphatic system [5]. The main categorization of cancers comprises carcinoma, myeloma, sarcoma, lymphoma, leukemia and other mixed types. The roots of cancers include contact of carcinogenic chemicals and radiation, gene mutation, environmental pollution, heredity, smoking, consumption of alcohol, food habits, etc. Cancer can occur when functions of oncogenes and tumor suppressor genes go inactive by gene mutations, leading to uncontrolled cell growth. Examples of carcinogens include tobacco, gamma rays, car exhaust fumes, asbestos, etc. Beside these, several viruses like hepatitis B and C (causes of liver cancer), human papillomavirus (a cause of cervical cancer), Epstein–Barr virus (a cause of some childhood cancers), and human immunodeficiency virus (HIV) can weaken the body’s immunity systems and can cause cancer. Every year, the American Cancer Society provides statistics on a number of new cancer patients, as well as the deaths of cancer patients in United States. Research in the areas of cancer diagnostics (preferably early detection),
prevention and treatment are really important, with the ultimate goal being the removal of cancer without damaging the normal tissue.

1.2 Conventional therapies for cancer and their limitations

The conventional therapies (chemotherapy, cancer vaccinations, photodynamic therapy, radiotherapy, stem cell transplantations, or a combination of these) have various limitations and side effects that make it necessary for scientists to develop an alternative treatment strategy using a more targeted approach. However, most of these strategies have several limitations. For example, surgery is limited to those tumors that are surgically resectable and accessible. Radiation therapy can damage healthy tissues surrounding cancerous tissues. It is very difficult to use PDT in case of deep tissue treatment as most photosensitizers cannot pass through more than 1 cm. Recognition of target antigens can be failed by faulty antigen presentation resulting in tolerance induction to the antigens and failure in the vaccination therapy. Chemotherapy has several severe limitations, including non-specificity, damaging healthy cells and tissue, toxicity of anticancer drugs in other organs and poor bio-availability, as well as fast clearance, drug resistance, highly expensive and ineffectiveness in case of metastasis.

The market value of global cancer therapeutics was about ∼US$110.6 billion in 2013 with an annual growth of 12.6%, as published in reports by BCC Research [6]. In this scenario, an economically convenient and alternative treatment strategy has to be urgently adopted for the treatment of cancer disease, rather than the existing orthodox therapeutic approaches. In this context, nanotechnology can have a significant role to overcome the limitations of conventional treatment strategies. In this book, we mainly focus on the potential application of anti-angiogenic nanoparticles and nanoparticles based drug delivery systems for cancer therapy and discuss the current status with a nanotechnology point of view and future prospect and challenges. In this perspective, nanobiotechnology can play a noteworthy role in overcoming the boundaries of unadventurous therapeutic strategies.

1.3 Alternative theranostics strategy: nanomedicine

The progress of nanoplatform technologies has been broadly touted as a ground-breaking paradigm shift for cancer theranostics applications. In nanotechnology, nanoparticles basically deal with particles having 1–100 nm size. The nanoparticles show unusual physical, chemical and optical properties from their bulk counterparts. Nanotechnology defines the research and technology that works at the nanometer scale (1–100 nm) [7]. Nanotechnology is the most promising area of modern science where the size of the matter can be controlled in the atomic, molecular, or macromolecular range with fundamentally new properties (physical, chemical, biological and optical) and functions due to small size, higher surface to volume ratio, surface energy, and aspect ratio of the nanomaterials [8]. Nanomedicine is the medical and healthcare application of nanotechnology for the treatment of different diseases. Due to small size, these materials can effortlessly interact with cell membrane (cell membrane width: ~6–10 nm) and go into the cells (size: 10–30 μm).
After internalization, they can intermingle with cellular components (DNA: ~2.5 nm; proteins: ~1–20 nm; cell surface receptors: ~10 nm) and can be useful for diagnostic and therapeutic purposes in various diseases. Recently, several investigators demonstrated nanotechnology-based diagnostic (bio-imaging, biosensing, MRI-imaging) and therapeutic (drug delivery, anticancer, antibacterial, photodynamic therapy) approaches for the treatment of several diseases (cancer, cardiovascular diseases, diabetes, Parkinson’s, spinal cord injury, tuberculosis, etc).

According to various sources, the global value of the nanomedicine market is close to US$177.60 billion in 2019. Various nanomaterials, such as inorganic nanoparticles (gold, silver, platinum), carbon nanotubes, fullerenes, dendrimers, liposomes, and polyplexes, have been widely examined for their biomedical applications (figure 1.1) [9–17]. As the nanomedicine industry continues to expand, it is predicted to have a noteworthy impact on healthcare, medicine and economy.

Figure 1.1. Schematic representation of different theranostics nanomedicine approaches in lung cancer theranostics. Reproduced with permission from [18]. CC BY 4.0.
The National Cancer Institute (NCI) has acknowledged nanotechnology as a budding field having huge potential to transform medicine for diagnosis, imaging, treatment and the prevention of cancer [19]. Nanotechnology can have a noteworthy role to prevail over the limitations of conventional treatment strategies [20]. The use and application of nanotechnology in cancer therapy and diagnostics is termed as ‘Cancer Nanotechnology’ [21]. Nanotechnology is utilized for cancer in two wide areas: (i) the progress of nanoparticles, for the delivery of therapeutics drugs or imaging agents as a targeted manner to tumors, and (ii) innovative use of nanosensors for the detection of cancer. Combined, these nanotechnology-based discoveries could be the pilot to advance cancer theranostics (therapeutics + diagnostics).

1.4 Magnetic nanoparticles and cancer theranostics

The unique physico-chemical properties of magnetic nanoparticles (MNPs) including small size, MRI-contrast properties, easy synthesis, easy surface modifications, negligible toxicity, and biodegradability facilitate them to serve as excellent imaging contrast agents, diagnostic agents and drug delivery vehicles for cancer theranostics applications [22–24]. Several groups including ours have recently focused on developing multifunctional magnetic nanotheranostics platforms, combining both imaging and therapeutic properties that will assist regarding the development of tailored medicine with the capacity of real time monitoring of disease prognosis. Hence, there is a constant need for the design and development of specific engineered MNPs according to the requirement of the theranostics point of view. MNPs act as proficient magnetic resonance imaging (MRI) contrast agents, due to elevated magnetization in an outer magnetic field and outstanding T2/T2* relaxation properties [25]. Generally, superparamagnetic magnetic nanoparticles including superparamagnetic iron oxide nanoparticle (SPIONs) conjugates are made of a magnetite core that provides much needed MRI contrast properties and an external biocompatible polymer coating required for the conjugation of therapeutic agents and tumor targeting moieties. Moreover, due to low toxicity and high biodegradability, MNPs were extensively used for several biomedical applications including biosensors, MRI imaging, drug delivery, tissue repair, magnetic hyperthermia, photothermal ablation therapy, cancer theranostics, etc [26–32].

As a large pool of researchers have synthesized a library of highly engineered MNPs and demonstrated their specific cancer theranostics applications, it is an urgent requirement to gather and represent all the recent information as a comprehensive review form. In the present review, we have focused on providing a detailed overview about the cancer theranostics applications of MNPs. In addition, we have highlighted the present challenges for clinical translation and future scopes of MNPs in cancer theranostics applications.

References

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