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REVIEW

Polymer-functionalized carbon nanotubes in cancer therapy: a review

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Abstract The increasing importance of nanotechnology in the field of biomedical applications has encouraged the development of new nanomaterials endowed with multiple functions. Novel nanoscale drug delivery systems with diagnostic, imaging and therapeutic properties hold many promises for the treatment of different types of diseases, including cancer, infection and neurodegenerative syndromes. Carbon nanotubes (CNTs) are both low-dimensional sp^2 carbon nanomaterials exhibiting many unique physical and chemical properties that are interesting in a wide range of areas including nanomedicine. Since 2004, CNTs have been extensively explored as drug delivery carriers for the intracellular transport of chemotherapy drugs, proteins and genes. In vivo cancer treatment with CNTs has been demonstrated in animal experiments by several different groups. Herein, the recent works on anticancer drug delivery systems based on carbon nanotubes are reviewed and some of more specific and important novel drug delivery devices are discussed in detail. This paper focuses on modifications of CNTs by polymers through covalent and non-covalent attachments: two different methods as critical steps in preparation of anticancer drug delivery systems from CNTs. In this respect the in vivo and in vitro behaviors and toxicity of the CNTs modified by polymers are summarized as well. Well-functionalized CNTs did not show any significant toxicity after injection into mice. Moreover, administration and excretion of CNT-based nanocarriers are discussed. It was concluded that future development of CNT-based nanocarriers may bring novel opportunities to cancer diagnosis and therapy.

Keywords Carbon nanotubes · Drug delivery · In vivo and in vitro behaviors · Cancer therapy

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Introduction

In the last decades, nanomaterials show new opportunities for drug delivery systems and provide targeted delivery and bioavailability, as well as solubilizing and improving the pharmacological profile of drugs [1]. Without using a nanocarrier for delivery of drugs, the efficacy of a treatment depends on physico-chemical properties and ability of drugs to reach a target site. In general, these systems can deliver drugs selectively to specific compartments without adversely affecting the surrounding tissues. Currently, the most reported nanocarriers are based on self-assembling polymeric nanostructures [2–4], functionalized magnetic nanoparticles [5–7], mesoporous silica [8–10] and carbon nanotubes [11–13] (Fig. 1).

CNTs are rolled up seamless cylinders of graphene sheets, exhibiting unparalleled physical, mechanical and chemical properties which have attracted tremendous interest in the past decade [14–16]. Depending on the number of graphene layers constituting a single nanotube, CNTs are classified as single-walled carbon nanotubes (SWNTs) or multi-walled carbon nanotubes (MWNTs) (Fig. 2). CNTs have found interesting applications in composite materials [17, 18], nanoelectronics [19–21], field-effect emitters [22, 23] and hydrogen storage [24,