Editorial

Nano-Carbons as Theranostics

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Abstract

Nano-carbons, including fullerenes, carbon nanoparticles, carbon nanotubes, graphene, and nano-diamonds, are an important class of nanostructures attracting tremendous interests in the past two decades. In this special issue, seven review articles and research reports are collected, to summarize and present the latest progress in the exploration of various nano-carbons for theranostic applications.

Key words: nano-carbons, biological sensing, imaging, drug delivery, cancer therapies, toxicology

The rapid development in nanoscience and nanotechnology has brought great opportunities to biomedical research in various directions. Among numerous types of nanomaterials developed in the past many years, carbon nanomaterials, or nano-carbons, have attracted particular interests in a large variety of fields including biomedicine [1-5], owing to their highly-enriched distinctive physical and chemical properties.

Based on their bonding structures, nano-carbons may be classified into sp^2-carbon nanomaterials and sp^3-carbon nanomaterials (Fig. 1). Typical sp^2-carbon nanomaterials include zero-dimensional (0D) fuller-ene, one-dimensional (1D) carbon nanotubes (CNTs), and two-dimensional (2D) graphene, all with well-defined structures. Remarkably, the discoveries of fullerene and graphene have been awarded with Nobel prizes in 1996 (Chemistry) and 2010 (Physics), respectively. Carbon nanoparticles or carbon dots (CDots), are nano-clusters of amorphous carbon (or composed by small crystalline structures) with sizes smaller than 10 nm, and may also be deemed as a type of 0D sp^2-carbon nanomaterials. Sp^3-carbon nanomaterials, on the other hand, usually are nano-diamonds (NDs) with crystal sizes in the nano-range.
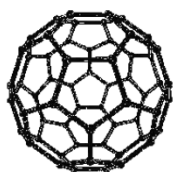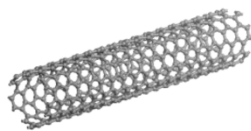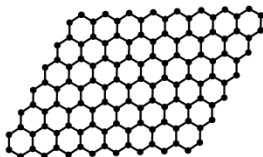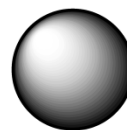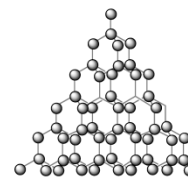

Figure 1. Different types of nano-carbons explored for theranostic applications.

There are many motivations and reasons of using nano-carbons for biomedical applications (e.g. theranostics). Many nano-carbons, including CNTs, graphene derivatives, Cdots, and NDs, show interesting inherent optical properties such as fluorescence, making them useful contrast agents in optical imaging and sensing [6-11]. The excellent electrical properties of CNTs and graphene, on the other hand, allow them to be extensively used in a wide range of biosensing platforms [12-14]. Sp^2-carbon nanomaterials especially single-walled carbon nanotubes (SWNTs) and graphene with all carbon atoms exposed on their surfaces, exhibit ultra-high surface area available for efficient drug loading and bioconjugation[1, 10, 15, 16]. For fullerene and CNTs with hollow structures, the inside space may be utilized to load other functional species for theranostic purposes[17-20]. CNTs and graphene derivatives with strong optical absorbance in the near-infrared region are also useful for photothermal ablation of cancer[21-25]. Moreover, compared with many other inorganic nanomaterials such as quantum dots (QDs) which usually contain heavy metals, nano-carbons composed simply by carbon are relatively safe at least in term of elementary composition.

In this special issue, we invite colleagues worldwide who have been exploring biomedical applications of nano-carbons for years, to discuss and report cutting-edge research in the use of nano-carbons as theranostics:

In the first article, Chen et al. [26] offer a comprehensive review to summarize the applications of functionalized fullerenes in tumor theranostics. Functionalized fullerenes have not only shown potential in several different cancer therapeutic approaches such as photodynamic therapy, photothermal treatment, radiotherapy and chemotherapy, but also been used as novel contrast agents in magnetic resonance (MR) imaging. The biodistribution, metabolism and toxicity of those functionalized fullerenes are also reviewed in this article.

In the following section, three articles are collected to highlight the promise of using CNTs for potential disease theranostics. Mandal et al. [27] report a label-free real-time electrical detection of whole viruses using CNT think film field effect devices, and achieve an ultra-high sensitivity which is 5 orders of magnitude higher than traditional electrical impedance sensors without CNTs. In the next article, Xu and co-workers [28] present an interesting study to investigate the influence of oxidized multi-walled carbon nanotubes (o-MWNTs) on marcophages. It is uncovered that subcutaneous injection of o-MWNTs would lead to macrophage reduction and decreased vessel density in the tumor by competing with the tumor mass for recruitment of macrophages from circulating monocytes, resulting in the inhibition of tumor progression and metastasis. This finding presents a novel approach of using CNTs in cancer immunotherapy. Besides these two research articles, a review article is contributed by Yang et al. [29] to discuss the pharmacokinetics, metabolism and toxicity of CNTs in details. Surveying others reports and the authors' own findings, it is summarized that the surface chemistry of CNTs is crucial in regulating the in vivo behaviors of CNTs. Compared with non-functionalized CNTs, well functionalized CNTs (e.g. by PEGylation) by both covalent and non-covalent methods are much less toxic in vitro and in vivo, and may be preferred for applications in biomedicine. However, the authors also point out that future studies are still needed to systematically evaluate long-term toxicity of CNT-exposure. Establishing fast and reliable analytical tools to study in vivo behaviors of CNTs as well as other newly developed nanomaterials is also of great importance.

Graphene has been a shining star in materials science since 2004. Its applications in biomedicine have also aroused widespread interest. In the article by Zhang and co-workers [30], the authors summarize the latest progress of applying graphene and graphene derivatives in various directions of biomedicine including drug and gene delivery, cancer therapies, biomedical imaging, biosensing, as well as tissue engineering scaffolds. The opportunities and challenges in this rapidly developing field are also discussed.

Cdots are surface-functionalized small carbon nanoparticles, which with certain modification, would emit bright fluorescence useful in biomedical imaging. In the article by Sun and co-workers [31], highly fluorescent Cdots without and with ZnS doping are prepared and evaluated for optical imaging in mice. Significantly, competitive performance of Cdots in vivo to that of well-established CdSe/ZnS QDs is observed, suggesting that Cdots may be a new class of non-heavy-metal containing optical probes promising in bioimaging.

In additions to sp^2-carbon nanomaterials, NDs with sp^3-bonded structure have also been extensively explored in nanomedicine. The last article of this issue is contributed by Zhu et al. [32] to review the in vitro and in vivo toxicity of NDs as well as their applications in drug delivery systems. With rather different properties and behaviors from sp^2 carbon nanomaterials such as CNTs and graphene, NDs and ND-clusters appear to be relatively safe in biological systems and are also potential candidates as drug

carriers for fluorescent imaging guided delivery.

In summary, the development of novel theranostic approaches based on nano-carbons has been and would remain to be an area attracting great attention in the field of nanomedicine. This special issue containing 4 review articles and 3 original research reports covers all widely explored nano-carbons in biomedicine. At this point, we would like to thank all the authors for their excellent contribution in this project, and hope that our issue would be informative and beneficial for researchers working in or interested in this area!

Conflict of Interest

The authors have declared that no conflict of interest exists.

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