Carbon dots interactions with the immune system: from imaging to biomedical applications

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Abstract

Carbon dots (CDs) are emerging as a class of versatile nanomaterials with unique physicochemical and biological properties, including tunable fluorescence, high water solubility, biocompatibility, and facile surface functionalization [1–3]. These nanoparticles, typically less than 10 nm in size, are gaining increasing attention for their potential applications in bioimaging, drug delivery, biosensing, and immunotherapy. Of particular interest is their interaction with immune cells, as this interaction underpins their immunomodulatory effects and their potential therapeutic applications in immunology and nanomedicine.[4–6] The interaction between CDs and immune cells is influenced by several factors, including the size, shape, surface charge, functional groups, and chemical composition of the CDs.[7] Surface engineering, such as doping with elements like nitrogen or sulfur or attaching specific functional groups, further modulates their interaction with immune cells. In my talk I will share critical insights on the impact of CDs on peripheral blood mononuclear cells (PBMCs), including immune cell activation, cytokine production, biocompatibility and immune responses, depending on the CDs' properties and the biological context. Studies have shown that CDs can activate macrophages and dendritic cells, leading to increased secretion of pro-inflammatory cytokines and enhanced antigen presentation. These properties position CDs as promising candidates for cancer immunotherapy and vaccine delivery, where robust immune activation is desirable. Functionalized CDs can also serve as carriers for antigens, adjuvants, or drugs, enabling targeted modulation of immune responses. For example, CDs conjugated with tumor antigens can enhance immune system recognition and facilitate tumor eradication. Conversely, certain CDs demonstrate immunosuppressive effects, making them valuable for managing inflammatory and autoimmune diseases. Surface modifications, such as the addition of polyethylene glycol (PEG) or other hydrophilic groups, can attenuate immune activation and reduce cytokine release. This dual capability to either stimulate or suppress the immune system highlights the versatility of CDs in diverse therapeutic applications. Understanding the dose-dependent effects of CDs and their long-term biodistribution is essential for ensuring their safe application in clinical settings. Furthermore, CDs' intrinsic fluorescence properties enable real-time imaging of immune cell interactions, providing insights into the dynamics of immune responses at the nanoscale. Such imaging capabilities facilitate the study of immune cell trafficking, activation, and interactions with other cell types in vivo. This feature makes CDs not only therapeutic agents but also powerful tools for immunological research. In conclusion, the interaction of CDs with immune cells represents a promising frontier in nanomedicine. Advancing this field requires an interdisciplinary approach to optimize CDs' design, minimize toxicity, and harness their immunomodulatory capabilities. Our results will pave the way for CDs to revolutionize immunotherapy, diagnostics, and regenerative medicine, with transformative impacts on healthcare.

References

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