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Nanoparticles and Near-Infrared Triggering for Biomedical Applications

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Introduction

The last decade has seen significant progress in the biomedicine applications of lanthanide-doped upconverting nanoparticles (UCNP) due to their unique properties under near-infrared (NIR) light. Advances in polymer, dye, and bio-molecule conjugation techniques on the surface of nanoparticles have expanded their dynamic opportunities for optogenetics, oncotherapy, and bioimaging. UCNPs' primary advantages, such as their lack of photobleaching, photoblinking, and autofluorescence, not only facilitate the development of accurate, sensitive, and multifunctional nanoprobes, but also improve therapeutic and diagnostic results. With a basic understanding of upconversion, we introduce the unique properties of UCNPs and the mechanisms involved in photon upconversion, and we discuss how UCNPs can be used in biological practises. We divide the applications of UCNP-based strategies into the following domains in this focused review: neuromodulation, immunotherapy, drug delivery, photodynamic and photothermal therapy, bioimaging, and biosensing. We also discuss current emerging bioapplications that use cutting-edge nano-/biointerfacing of UCNPs in this paper. Finally, this review concludes with thoughts on future opportunities and challenges in clinical translation of UCNPs-based nanotechnology research.

Description

For a long time, light-emitting nanoparticles have made significant contributions to biology and biomedical research. For example, luminescent probes are used for protein localization and monitoring biological processes. In-vivo biological applications of quantum dots and downconversion nanomaterials fail in terms of penetration depth in bio-specimens, and the common drawbacks of these materials are light scattering, low intensity, high photo-damage, poor photo-stability [1], and background autofluorescence, making them unsuitable for meeting the challenges of frontier biological science. As a result, developing novel nanophotonic systems with enhanced features such as deep tissue penetration, reduced cytotoxicity, and low cell damage for a variety of biomedical applications is critical. Rare earth (RE)-doped UCNPs can convert low-energy photons into high-energy photons via successive absorption [2], overcoming many of the disadvantages associated with short-wave (ultra-violet or visible) excitation. In RE-doped inorganic materials, where the RE ions act as luminescent centres, photon upconversion occurs. It is worth noting that upconversion is accomplished with low-intensity, low-cost, and easily accessible lasers, which has advantages over second harmonic generation and two-photon absorption, which require high-power and expensive laser sources [3].

With advances in nanotechnology for the preparation of small, high-quality, and bright nanoparticles in the early 2000s, studies on the biological applications of UCNPs were initiated. Excellent light emission properties, such as tunable excitation dynamics, a large anti-Stokes shift, sharp emission bands, and so on, are ideal for pioneering nanomedicine platforms [4]. Following that, UCNPs have been widely used in a wide range of advanced biological applications, including background noise-free biosensing, precision nanomedicine, deep-tissue imaging, cell biology, visual neurophysiology, and optogenetics. With our extensive knowledge of upconversion kinetics, we have recently been able to engineer the shape and size of nanoparticles for precise photoluminescence properties [5]. The wavelength of the emission peaks and their relative intensity, for example, can be manipulated by synthesising core multi-shell nanostructures and varying the concentration and type of RE dopants. Furthermore, the UCNPs can produce orthogonal emissions in response to two separate NIR excitations. It's worth noting that, due to the REs' ladder-like energy levels, certain ions can even show efficient upconversion in the second NIR window [6]. Thus, the UCNPs can be used for newer biological applications such as intracellular signalling and deep-tissue bioimaging using NIR-II. Although some literature reviews on advances in the synthesis and general applications of UCNPs are already available, a focused review on recent breakthroughs in this field is required in light of biomedicine applications. As a result, this article discusses the current progress in biomedicine application of UCNPs, as well as the real challenges and perspectives. We begin with a basic understanding of photon upconverting nanoparticles, including the mechanisms for upconversion luminescence, in this review paper. The advancement of UCNPs in biomedicine applications such as optogenetic modulation, immunotherapy, drug delivery, photodynamic/thermal therapy, bioimaging, and biosensing is then thoroughly reviewed. The final section of this review article also discusses the conclusion, future perspectives, and challenges for clinical translation.

Conclusion

Because of safety concerns, UCNP applications (in vitro and in vivo) are restricted to the laboratory. The chemical composition of UCNPs may have toxic effects. The size of the UCNPs should be optimised based on their interactions with cells, which necessitates a fully reproducible and standard synthesis method, as well as long-term suspension stability in biological media at 37°C. End users should follow proven safety data. To bridge the laboratory-to-clinical translational gap, a risk-benefit analysis of theranostic applications is essential. To summarise, biomedicine applications of UCNPs have great potential, but they face several challenges. We anticipate that scientists' collaborative efforts will result in a broad and bright future in its prospect, paving the way in the right direction for the prospects of UCNPs' biological applications.

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Conflict of Interest

None

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