Magnetic nanoparticles, a new ally in immunobiotherapies

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Harnessing the immune system to combat cancer has become one of the most transformative directions in modern medicine. While immunotherapies such as CAR T cells and immune checkpoint inhibitors have achieved remarkable success in hematological malignancies, their translation to solid tumors remains a major challenge. This limitation is largely driven by the immunosuppressive tumor microenvironment and by physical barriers—such as dense, fibrotic stroma—that restrict immune cell access and function. Addressing these obstacles requires new tools capable not only of activating immune responses, but also of monitoring, guiding, and dynamically reprogramming them in vivo.

In this context, magnetic and plasmonic nanoparticles offer a uniquely versatile platform at the interface of physics, materials science, and immuno-oncology. In this lecture, I will discuss how iron oxide–based and gold-functionalized magnetic nanomaterials can be leveraged—alone or in combination with external stimuli such as magnetic fields or light—to both track and control immune responses with high spatiotemporal precision.

First, I will demonstrate how iron oxide nanoparticle labeling enables the non-invasive tracking of CAR T cells by MRI over extended periods in vivo. Beyond imaging, magnetic actuation provides a means to actively guide these cells toward tumors, significantly enhancing their infiltration and therapeutic efficacy. This dual imaging–actuation capability illustrates the power of magnetic nanoparticles as both diagnostic and therapeutic agents (1).

Second, I will present a high-throughput screening platform designed to evaluate the immunomodulatory properties of metallic nanoparticles and ions. By integrating laser activation with advanced data analysis, we uncover switchable macrophage polarization states, enabling controlled transitions from immunosuppressive to pro-inflammatory phenotypes. These findings open new avenues for designing stimuli-responsive nanomaterials that precisely tune immune function (2).

Third, focusing on highly fibrotic tumors such as cholangiocarcinoma, I will show how magnetic-plasmonic nanostructures can be used in combinatorial therapies. Photothermal activation of gold-decorated iron oxide nanoflowers, coupled with PD-1 checkpoint blockade, remodels the tumor stroma, reduces mechanical stiffness, and promotes immune cell infiltration. This approach effectively converts immune-resistant “cold” tumors into “hot,” responsive ones, highlighting the potential of nanotechnology to overcome key barriers in solid tumor immunotherapy (3).

Finally, I will explore the emerging field of extracellular vesicle–based therapies. By using magnetic nanoparticle preconditioning, we generate vesicles that are both MRI-visible and magnetically responsive, enabling their tracking and remote functional modulation. These engineered vesicles exhibit enhanced immunoregulatory activity, which can be further amplified under magnetic stimulation, offering a new paradigm for cell-free, controllable immunotherapies (4).

Altogether, this work positions magnetic nanoparticles not merely as passive carriers, but as active, multifunctional agents capable of sensing, guiding, and reprogramming immune responses. I will conclude by discussing the opportunities and challenges for translating these approaches toward

clinical applications, and the broader role of magnetic nanotechnology in shaping the future of precision immunotherapy (5).

References:

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