Multiscale Optical Imaging for Analyzing the Dynamic Behavior of Immune Cells in the Tumor Microenvironment

Fuqiang Ren
Ganjiang Innovation Academy, Chinese Academy of Sciences, Beijing, China

Hongjie Dai
Ganjiang Innovation Academy, Chinese Academy of Sciences, Beijing, China

Abstract

Tumor immunotherapy represents a major breakthrough in medicine, earning the 2018 Nobel Prize in Medicine for its significant contributions. This treatment approach activates the patient's immune system to recognize and eliminate tumor cells. Immune checkpoint inhibitors, such as anti-PD-1 and anti-CTLA-4 antibodies, have shown promising efficacy in treating cancers like melanoma, lung cancer, and pancreatic cancer. However, their clinical response rate remains low at only 10%-40%, meaning that many patients fail to benefit from treatment. This highlights the urgent need for early and accurate assessment of patient response to avoid ineffective therapies. Currently, immune therapy efficacy is mainly evaluated using in vitro techniques such as flow cytometry and immunofluorescence, which fail to provide real-time, dynamic insights into immune cell behavior in vivo. In contrast, second near-infrared (NIR-II) imaging offers superior tissue penetration and reduced autofluorescence, making it a powerful tool for monitoring immune responses. Researchers can label immune checkpoint inhibitors or immune cells with NIR-II nanoprobes and use NIR-II imaging to track their distribution and dynamics within tumor tissues in real-time[1, 2]. This approach not only provides high-resolution 3D imaging but also enables in-depth evaluation of immune cell infiltration and tumor-targeting effectiveness. Such advancements are critical for early assessment of immunotherapy efficacy, allowing clinicians to optimize treatment strategies and improve therapeutic outcomes.