

Microfluidic Immunoassay Using Encoded Microparticles for Low-Volume Multiplex Detection of Cancer-Associated Proteins

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Abstract

Multiplexed detection of tumor-associated proteins is a critical requirement for improving cancer diagnosis and therapeutic monitoring, as cancer progression is inherently heterogeneous at the molecular level. Optical biosensing strategies integrated with microfluidic platforms offer unique advantages for sensitive, parallel biomarker analysis using limited clinical samples. In this work, we report a microfluidic immunoassay system that leverages optically encoded microparticles to enable simultaneous detection of multiple cancer-related proteins within a single assay format.

The platform utilizes uniquely encoded polymeric microparticles, each functionalized with capture antibodies specific to a target biomarker, allowing multiplex identification through optical decoding. Prostate-specific antigen (PSA), carcinoembryonic antigen (CEA), and interleukin-6 (IL-6) were selected as representative tumor-associated proteins due to their clinical relevance across different cancer types. The encoded microparticles were integrated into a microfluidic chip that supports controlled particle handling, reagent delivery, and washing steps, enabling a streamlined immunoassay workflow compatible with automated operation.

Optical readout was performed by decoding the microparticle identities and quantifying fluorescence signals corresponding to bound target proteins. Owing to the combined benefits of microparticle-based signal amplification and microfluidic confinement, the system achieved detection limits spanning the femtogram-to-picogram per milliliter range while requiring only a few microliters of plasma per assay. Analytical performance was assessed using human plasma samples obtained from cancer patients and healthy donors. The multiplexed assay demonstrated a clear capability to differentiate patient samples from healthy controls based on combined biomarker profiles.

In comparison with conventional single-analyte immunoassays, the proposed approach substantially reduced sample volume requirements while providing enhanced sensitivity and multiplexing capacity. The optical encoding strategy further enabled robust target discrimination without increasing assay

complexity, highlighting its suitability for high-throughput and miniaturized diagnostic platforms.

Overall, this study demonstrates the feasibility of integrating optically encoded microparticles with microfluidic immunoassays for sensitive, low-volume, and multiplexed protein analysis. The presented system shows strong potential for future biophotonic diagnostic applications, including automated point-of-care testing and translational cancer biomarker analysis.