A Dual-Field Inertial–Acoustic Microfluidic Chip for Label-Free Circulating Tumor Cell (CTC) Isolation

Chen, Feiqi (Carl) (School: Culver Academies)

Circulating tumor cells (CTCs) are rare cancer-derived cells in the bloodstream and serve as important biomarkers for early cancer detection and monitoring. However, current clinical methods, such as the FDA-approved CellSearch system, rely on marker-based capture and suffer from high cost, operational complexity, and limited accessibility. Existing microfluidic approaches offer label-free alternatives but are often limited by single-field separation efficiency and instability caused by particle–wall interactions. This project presents the design and validation of a dual-field inertial–acoustic microfluidic chip for label-free CTC isolation. Inertial focusing is first used to pre-align particles based on size-dependent lift forces and Dean flow effects, followed by acoustic manipulation to further separate particles through size-dependent acoustic radiation forces. To address stability challenges, a hybrid anti-adhesion strategy combining micropillar structures and surface modification is incorporated to reduce fouling and enable sustained operation. Experimental validation was conducted using fluorescent microspheres (2–20 μm) as cell analogs under controlled flow conditions. Results demonstrate over 96% enrichment efficiency in the inertial stage, with further improvement in separation performance under acoustic activation. The optimized trifurcation outlet design enhances spatial resolution of particle streams, enabling effective separation of target and non-target populations. This work demonstrates a low-cost, label-free, and scalable microfluidic platform with potential applications in early cancer detection and point-of-care diagnostics.

Awards Won:

Fourth Award of $600