Supplementary Material (ESI) for Lab on a Chip

Activated T Lymphocytes Migrate Toward the Cathode of DC Electric Fields in Microfluidic Devices

Jing Li, Saravanan Nandagopal, Dan Wu, Sean F. Romanuik, Kausik Paul, Douglas J. Thomson and Francis Lin

Department of Physics and Astronomy
University of Manitoba
Winnipeg, MB
R3T 2N2, Canada

Supplemental Data

1. Cell migration data analysis methods

As illustrated in Fig. S1, the movement of cells in microfluidic devices was quantitatively evaluated by (1) the percentage of cells that migrated toward the cathode of the electric field for electrotaxis experiments, or toward CCL19 gradient in chemotaxis experiments; (2) the Orientation Index (O.I.), which is the ratio of the displacement of cells toward the cathode of the electric field in electrotaxis experiments (Δx) or toward the CCL19 gradient in chemotaxis experiments (Δy), to the total migration distance (d) using the equation O.I. (electrotaxis)= $\Delta x/d$, and O.I. (chemotaxis) = $\Delta y/d$, presented as the average value ± standard error of the mean (SEM); (3) the motility index (M.I.), defined as normalized cell displacement and presented as the average value ± SEM; (4) the average speed (V) calculated as $d/\Delta t$ and presented as the average value ± SEM; and (5) statistical analysis of migration angles performed using Oriana for Windows (Kovach Computing Services) to examine the directionality of the cell movement.

2. Modeling and simulation of electric fields in microfluidic devices

To characterize the electric fields in microfluidic devices, we performed modeling studies and computer simulations using COMSOL® Multiphysics v3.4 with the AC/DC Generalized Electrostatics Module. A 7V DC voltage was applied to the 1cm long PDMS microfluidic channel through a pair of platinum electrodes. As shown in Fig. S2, the simulation shows the uniform electric field (671.4 V/m) and current density (978.9 A/m^2) inside the PDMS microfluidic channel. This current density predicts a total current of 34.26 μA, which agrees nicely with the experimentally measured current (34 μA). Similarly, the simulation shows the uniform electric field (818.8 V/m) and current density (1194 A/m^2) in the straight region of the glass microfluidic channel where cell migration is imaged (Fig. S3). The electric field and current density are not uniform in the curved region of the channel. Thus, our microfluidic devices can produce uniform DC electric fields in defined regions of the microfluidic channel for electrotaxis studies.

3. Chemotaxis and electrotaxis of T cells in microfluidic devices

Using the PDMS microfluidic device, we tested chemotaxis and electrotaxis of activated human T cells in a range of chemokine gradients and DC electric fields. Our results show the optimal chemotactic response in the 100nM CCL19 gradient and the optimal electrotactic response in the 7V/cm electric field (Fig. S4). Thus, the cell migration data in the 100nM CCL19 gradient and the 7V/cm electric field were used for further analysis and comparison.

4. Figure Legends

Fig. S1. Illustration of cell migration data analysis in microfluidic devices.

Fig. S2. Simulation of electric field in the PDMS microfluidic electrotaxis device. (A) Simulated electric field and current density inside the microfluidic channel. (B) Plot of simulated electric field along the length of the channel. The electric field is uniform except the region close to the medium reservoirs.

Fig. S3. Simulation of electric field in the glass microfluidic electrotaxis device. (A) Simulated electric field and current density inside the microfluidic channel. (B) Plot of simulated electric field along the length of the channel between the turnings. The electric field is uniform in the straight region of the channel.

Fig. S4. Chemotaxis and electrotaxis of activated human T cells in the PDMS microfluidic devices. (A) Orientation Index in different CCL19 gradients. The optimal chemotactic response occurs in the 100nM CCL19 gradient. (B) Orientation Index in different electric fields. The optimal electrotactic response occurs in the 7V/cm electric field. Thus, the cell migration data in the 100nM CCL19 gradient and the 7V/cm electric field were used for further analysis and comparison.

5. Movie Legends

Movie S1: Electrotaxis of activated human T cells toward the cathode (left) of a 7V/cm DC electric field inside a PDMS microfluidic channel over 20min.

Movie S2: Random migration of activated human T cells in medium inside a PDMS microfluidic channel over 20min.