Supporting Information for Negative Dielectrophoretic Capture and Repulsion of Single Cells at a Bipolar Electrode: the Impact of Faradaic Ion Enrichment and Depletion.

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Simulation of F_{DEP} near a bipolar electrode (BPE) tip in a microchamber. The simulation of Figure 1b (main text) was performed using COMSOL Multiphysics version 4.4 software. The geometry employed for the simulation was a 500 μm-long segment of a 20 μm-tall by 60 μm-wide microchannel. The microchannel had a 30 μm-long x 30 μm-wide x 20 μm-tall chamber embedded in the wall at the center of the microchannel segment.

Simulation parameters were as follows. The aqueous medium was modeled as a non-solid with relative permittivity of $\varepsilon_r = 80$. The channel walls (boundaries) were uncharged, to model a Pluronic-coated microchannel. The boundary defining the floor of the chamber was assigned an electric potential of 3.125 V. The inlet and outlet (left and right of Fig. 1b, respectively) were assigned 12.5 V and 0.0 V, respectively, yielding an average field strength of 25 kV/m.

Note that a DC electric field with no charge migration is implied by this simulation strategy, and the real system (Figure 1a, main text) comprises an AC electric field with mobile charge species. However, under AC electric field conditions, there is no electromigration or accumulation of charged species. Therefore, a DC electric field with no charge migration accurately approximates a time-averaged or root-mean-square (RMS) AC electric field.

The 3D geometry was divided into finite elements with a free tetrahedral mesh, having a maximum element size of 2.5 μm. A stationary linear solver determined the distribution of electric potential based on charge conservation. Finally, the resulting distribution of electric potential was used to derive the plot of the y-component of DEP force (Fig. 1b) using the following equation:

$$F_{\mathrm{DEP}} = 2\pi r^3 \varepsilon_0 \varepsilon_r \mathrm{Re}[\mathrm{K}(\omega)]\sqrt{(E_x^2 + E_y^2 + E_z^2)} * \mathrm{d}(\sqrt{(E_x^2 + E_y^2 + E_z^2)})/\mathrm{dy} \qquad \text{eq. S1}$$

Here, $\mathrm{Re}[\mathrm{K}(\omega)] = -0.5$, $r = 10$ μm, ε_0 is vacuum permittivity, and E_n is the magnitude of the electric field along the *n*th axis.

Repulsion of cells from an FID zone formed at the BPE anode in phosphate DEP buffer. Figure S1 is a series of optical micrographs showing negative dielectrophoretic (nDEP) repulsion of B-cells from a faradaic ion depletion (FID) zone formed at the BPE anode in phosphate DEP buffer (1 s/image). In this experiment, the device was prepared with 10 mM phosphate DEP buffer (DEP channel) and 10 mM NaCl (auxiliary channel). B-cells in phosphate DEP buffer were introduced into the DEP channel at a flow rate of $v_{\mathrm{avg}} = 80$ μm/s (left to right). An AC field with a *negative* DC offset was applied at V_3 such that $E_{\mathrm{RMS,avg}} = 8.0$ kV/m and $E_{\mathrm{DC,avg}} = 2.5$ kV/m DC. These electric field conditions are similar (but opposite in DC offset sign) to those employed in the repulsion experiment shown in Figure 4b (main text).

Water oxidation at the BPE anode followed by protonation of HPO_4^{2-} ions led to ion depletion around the BPE tip. DEP repulsion of cells from the BPE anode resulted. However, in this case, DEP repulsion worked against EP attraction of the cells. We observed that repelled cells moved with the FID zone boundary while other cells remained stationary. Importantly, DEP force is exerted only at the FID zone boundary where there is an electric field gradient. If a cell is not repelled as the boundary passes, then it will not be repelled at later time points and behaves much like a cell in a DC-only electric field. Note that in a control experiment under DC-only electric field conditions, at a BPE anode, cells were attracted toward the BPE became stationary at distances of 0 μm – 100 μm from the BPE.

These results are significant because when considered together with the results described in the main text (Figures 2, 3, and 4), they provide a complete picture of nDEP force at FID and FIE zone boundaries. Specifically, there are four nDEP regimes depending on the ionic strength near the BPE (FID or FIE) and the pole of the BPE employed (anode or cathode). They are as follows: FIE, anode, nDEP attraction, EP attraction (Fig. 2a – 2c, main text); 2) FIE, cathode, nDEP attraction, EP repulsion (Fig. 2d and 2e, main text); 3) FID, cathode, nDEP repulsion, EP repulsion (Fig. 3 and 4, main text); 4) FID, anode, nDEP repulsion, EP attraction (Fig. S1).

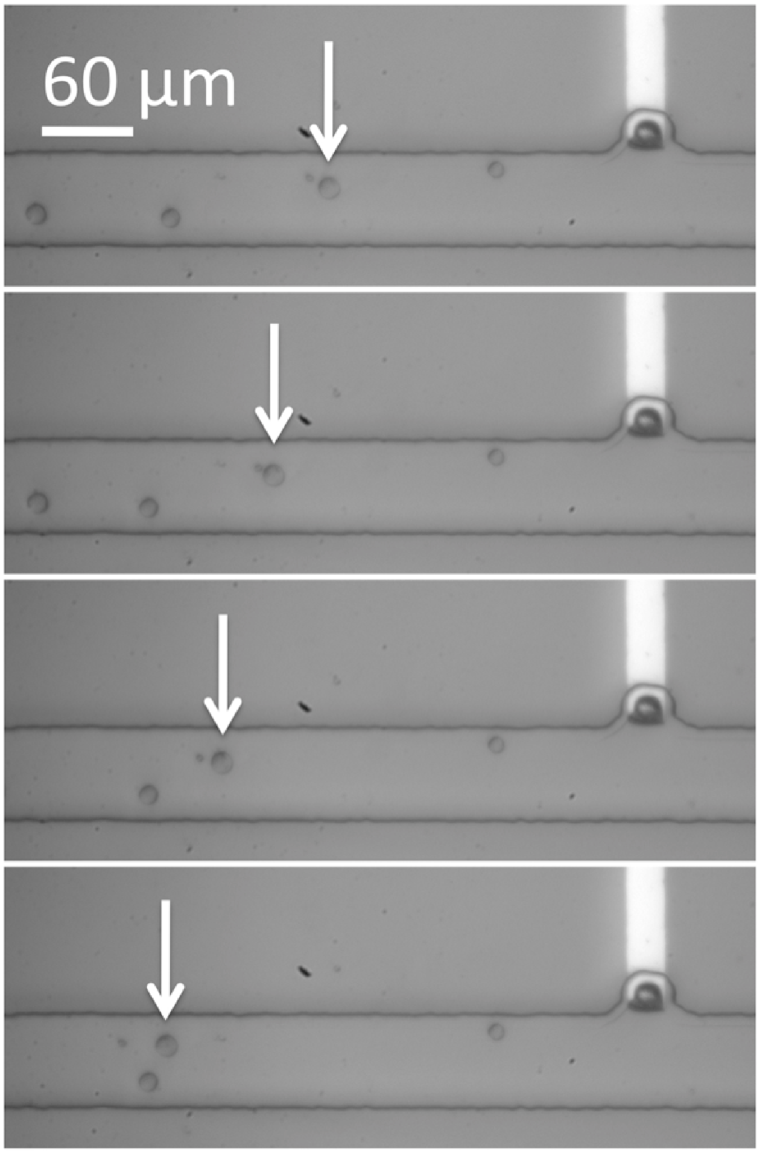

Figure S1. Arrows indicate one of the repelled cells. $E_{RMS,\,avg}$ = 8.0 kV/m and $E_{DC,\,avg}$ = 2.5 kV/m. ω = 1.8 kHz.

Repulsion of cells from an FID zone formed at the BPE cathode in Tris buffer under DC only electric field conditions. Movie 3 (4 frames/s) demonstrates electrophoretic (EP) repulsion (right to left) of B-cells from an FID zone formed at the BPE cathode in the presence of opposing flow (left to right). This experiment was performed using a microdevice similar to that described in the main text except for the following differences: each of the microchannels was 100 μm wide, the BPE was 15 μm wide, and the segment of the BPE in electrochemical contact with each microchannel was 40 μm long. As in previous experiments (main text), the electroosmotic flow was suppressed by coating the channel with Pluronic F108 in 10 mM Tris (pH 8.0) overnight at 4°C. Prior to initiating the cell repulsion experiment, the microchannels were rinsed with 10 mM Tris (pH 8.0) at 3 psi for 30 s.

Movie 3 shows an optical microscope top-down view of a segment of the microchannel near the BPE. The experiment proceeded as follows. First, the solution in the left-hand reservoir was replaced with 2 x 10^5 B-cells/mL in 10 mM Tris (pH 8.0), 8.0% sucrose, 0.3% dextrose, and 0.1% BSA. Then, the relative height of the solution in the reservoirs was adjusted to establish an average linear flow velocity (left to right) of 35 μm/s (~4 pN drag force). As a result, cells were carried into the channel. Finally, a DC driving voltage of 10 V was applied at the left-hand reservoir (V_3, Scheme 2c main text) versus ground (at V_1, V_2, V_4); $E_{\mathrm{DC,avg}}$ = 2.5 kV/m. As a result, this end of the BPE acted as a cathode, leading to FID zone formation (due to water reduction (eq. 3) and TrisH^+ neutralization (eq. 4)). As B-cells (which have net negatively charged cell membranes) were carried into the channel by convection (left to right), they encountered an increasing EP force (right to left) due to the enhanced electric field surrounding the BPE cathode. Therefore, the velocity of the cells decreased until they reached a balance point ~250 μm to the left of the BPE. This result is significant because it demonstrates EP repulsion of B-cells in the absence of DEP force, whereas Figures 4a and 4b (main text) demonstrate a combination of EP and DEP forces.