Electronic Supplementary Material (ESI) for Lab on a Chip

Rapid dielectrophoretic characterization of single cells using the dielectrophoretic spring

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Supplementary Material

Analytical expression for $q_R(x)$, which represents the positional dependency of the DEP force

An analytical expression for the electric field on a pair of coplanar electrodes in a micro channel has been derived as the following equation via a three-step transformation using conformal mapping. [1]

$$E(x,y) = \frac{1}{2}\frac{V_{eff}}{2K(k^2)}\overline{(1-v^2(u(x+iy)))(1-k^2v^2(u(x+iy)))^{-1/2}}\,\overline{(D-BC)/(D+Cu(x+iy))^2}\,\overline{\frac{\pi}{h}\cosh(\frac{\pi}{h}(x+iy-\frac{ih}{2}))} \quad \text{(Eq. S1)}$$

where the variable of B, C, D, k depends on the electrode gap(g), electrode width (W), and the channel height(h). The detailed expression for these variables and the f unctions u, v, K can be found in reference 1, which also provides Matlab scripts for computing the analytical solution of the electric fields.

From Eq. S1, and according to Eq. 3 of the main text, the expression of $q_R(x)$ is then as follows:

$$q_R(x) = \frac{\partial}{\partial x}\left[\left(\frac{E(x,y)}{V_{eff}}\right)^2\right]\Bigg|_{y=h-R} \quad \text{(Eq. S2)}$$

Reference

1. N. Demierre, T. Braschler, P. Linderholm, U. Seger, H. van Lintel, and P. Renaud, *Lab on a chip*, 2007, **7**, 355–65.

Image processing for obtaining the cell size

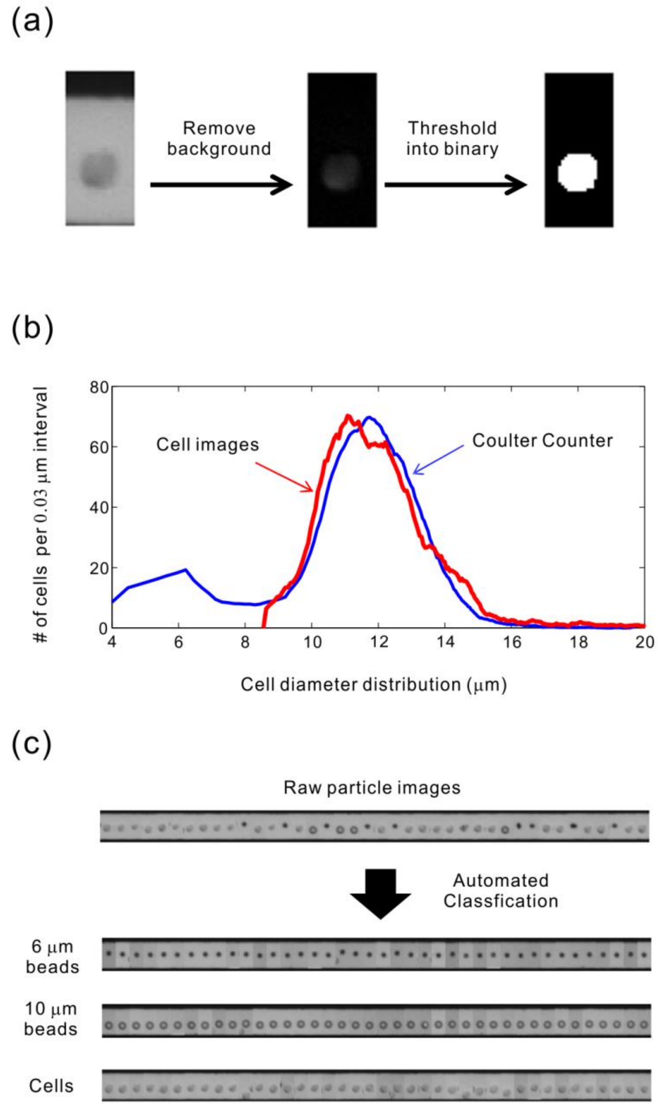

Fig. S1 The image processing routine (a) The raw image was subtracted by the background (from a median filter) and then transformed into binary image with the threshold of the normalized intensity of 0.05. (b) The comparison of cell diameter distribution of HL-60 cells obtained from Coulter Counter and calculated from the binary image. (c) The automated classification for categorizing 6 μm beads, 10 μm beads and HL-60 cells based on size and intensity.

Impedance of the microfluidic device

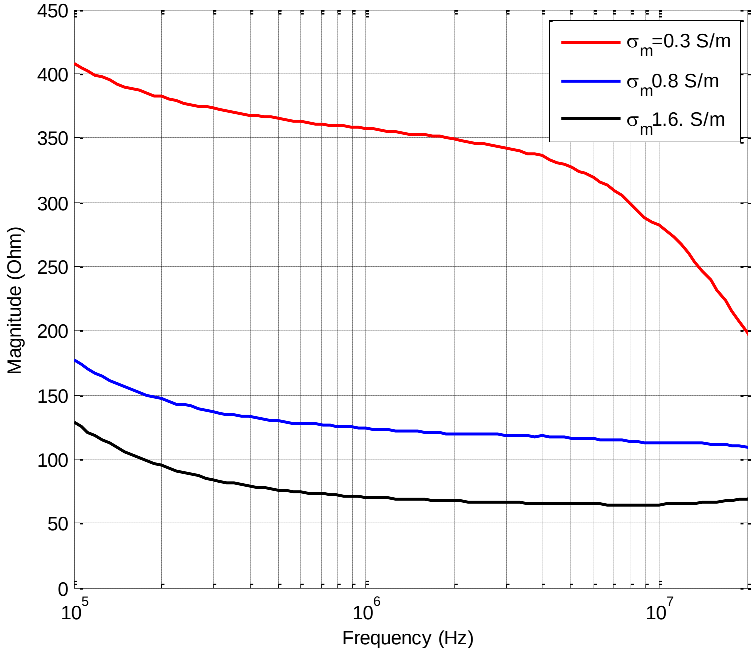

Fig. S2 The impedance magnitude of the device in different frequencies and different media conductivity.

Modeled CM factor for beads in various media conductivities

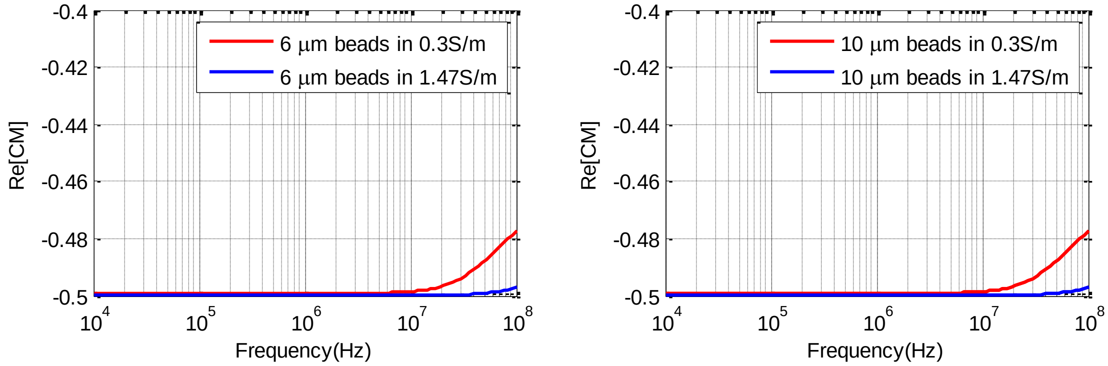

Fig. S3 The modeled Re[CM] for 6 μm and 10 μm polystyrene beads. In the HL-60 and neutrophil experiments, the Re[CM] are mostly -0.5. In 12.8MHz, the Re[CM] for both beads raise a little to -0.498, which we still assume to be -0.5. Therefore, we can use the bead to be the reference to calibrate the systematic parameter.

Validation of neutrophils activation after PMA treatment

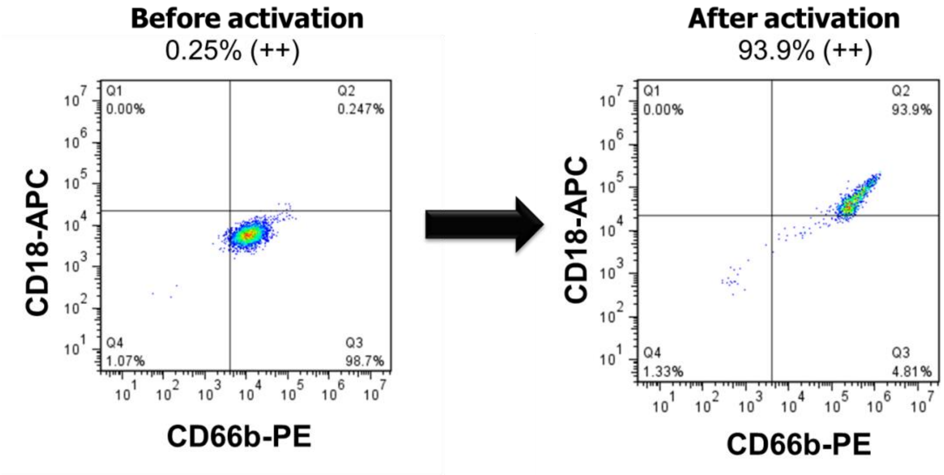

Fig. S4 The validation of neutrophils activation with flow cytometry. The isolated neutrophils were labeled with CD18-APC and CD66b-PE. The activation percentage is 0.25% for untreated neutrophils and the activation percentage is 93.9% after PMA treatment.

SI Table I Error analysis for simulation curve

Symbol	*Description*	*Value*	*Obtained from*	*Error*	*Error in b*	*Error in δ (um)*
Q	*Flow rate*	*(1,2,4)e-9/60*	*Syringe pump*	*± 0.35%*	*± 0.35%*	*~0*
w	*Channel width*	*1.98e-3*	*Measured from image*	*± 1%*	*± 1%*	*±0.05*
h	*Channel height*	*17-e6*	*Measured from Dektak (EML)*	*± 1%*	*∓3.4%*	*±1.6*
g	*Electrodes gap*	*13.6-6*	*Measured from image*	*± 5%*	*∓2.85%*	*∓0.15*
d	*Electrodes width*	*46e-6*	*Measured from image*	*± 2%*	*∓0.001%*	*±0.05*
R	*Particle radius*	*3.04e-6*	*Labeled from Polyscience beads*	*± 10%*	*± 13%*	*± 0.7*
v	*Voltage amplitude*	*(10,9,8,7,6,5,4,3)V*	*Function generator*	*±1%*	*±2%*	*±0.1*
θ	*Angle between the flow and electrodes*	*3.202°*	*Measured from image*	*± 5%*	*∓5%*	*∓0.6*
η	*Viscosity of the fluid*	*9.68e-4*	*Obtain from table*	*<± 10%*	*< ∓9%*	*< ∓0.6*
ε_m	*Media dielectric constant*	$80\ \varepsilon_0$ *=7.08e-10*	*Reference*[1]	*<± 3%*	*<±3%*	*<±0.15*
ε_p	*Particle dielectric constant*	$3.5\ \varepsilon_0$ *=3.10e-10*	*Reference*[1]	*<± 10%*	*< ∓0.1%*	*~0*
σ_m	*Media conductivity*	*~20mS*	*Measured from conductivity meter*	*<± 10%*	*<±0.43%*	*~0*
σ_p	*Particle conductivity*	*0.33-0.66mS*	*Reference*[1]	*±50%*	*∓0.2%*	*∓0.15*
p(f)	*Normalized frequency response*	*1*	*Electrical model*	*<-10%*	*<-10%*	*< -0.65*
C_{Wall}	*Correction Factor for the wall effect*	*1.77*	*Calculated from Ganatos formulation*[2]			

(Unit: SI unit)

Reference

1. W. M. Arnold, H. P. Schwan and U. Zimmermann, *J Phys Chem-Us*, 1987, **91**, 5093-5098.
2. P. Ganatos, R. Pfeffer and S. Weinbaum, *J Fluid Mech*, 1980, **99**, 755-783.