ELECTRONIC SUPPLEMENTARY INFORMATION

Manipulation of cancer cells in a sessile droplet via travelling surface acoustic waves

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Theoretical models for ARFs and drag force

Ideal ARF and drag forces can be employed to change the dependence of the behaviours on particle size and contact angle. The ASF-induced drag force (F_D) can be expressed as:

$$F_D = 3\pi\mu d_p u, \tag{S1}$$

and the ARF induced by standing waves (F_{RS}) as:[1, 2]

$$F_{RS} = \pi {d_p}^2 \kappa \Phi(\tilde{k}, \tilde{\rho}) E_{ac} \sin(2kx), \tag{S2}$$

where $\Phi(\tilde{k}, \tilde{\rho})$ is the acoustophoretic contrast factor, E_{ac} is the acoustic energy density, k is the acoustic wavenumber (= $2\pi f/c_f$), and x is the distance from the pressure node. The ARF induced by travelling waves (F_{RT}) can be expressed as:[3, 4]

$$F_{RT} = \frac{\pi {d_p}^2}{4} Y_T E_{ac}, \tag{S3}$$

where Y_T is the dimensionless ARF factor due to travelling waves. As shown in Fig. S2, 6 µm and 15 µm microparticles at low frequencies were subjected to lower F_{RT} levels than F_D and F_{RS} levels. Due to the relatively low azimuthal velocities within the sessile droplet,[5] a region predominantly influenced by standing wave-induced ARFs formed at the center and edge of the droplet.

The component of eqn (S2), which denotes acoustophoretic contrast factor, is defined as:[1, 2]

$$\Phi(\tilde{k}, \tilde{\rho}) = \frac{1}{3}\left(\frac{5\tilde{\rho} - 2}{2\tilde{\rho} + 1} - \tilde{k}\right), \tag{S4}$$

where the parameters $\tilde{\rho}$ and $\tilde{k}$ are written as:

$$\tilde{\rho} = \frac{\rho_p}{\rho_f}, \tag{S5}$$

$$\tilde{k} = \frac{\rho_f {c_f}^2}{\rho_p {c_p}^2}, \tag{S6}$$

where ρ_p is the density of the particle, ρ_f is the density of the fluid, c_f is the speed of sound in the fluid, and c_p is the speed of sound in the particle.

The component of eqn (S3), which denotes dimensionless ARF factor, is given by:[3, 4]

$$Y_T = -\frac{4}{\kappa^2} \sum_{n=0}^{\infty} [(n+1)(\alpha_n + \alpha_{n+1} + 2\alpha_n\alpha_{n+1} + 2\beta_n\beta_{n+1})], \tag{S7}$$

where κ is κ-factor, and α_n and β_n are defined as:

$$\alpha_n = -\frac{[F_n j_n(\kappa) - \kappa {j_n}'(\kappa)]^2}{[F_n j_n(\kappa) - \kappa {j_n}'(\kappa)]^2 + [F_n y_n(\kappa) - \kappa {y_n}'(\kappa)]^2}, \tag{S8}$$

$$\beta_n = -\frac{[F_n j_n(\kappa) - \kappa {j_n}'(\kappa)][F_n y_n(\kappa) - \kappa {y_n}'(\kappa)]}{[F_n j_n(\kappa) - \kappa {j_n}'(\kappa)]^2 + [F_n y_n(\kappa) - \kappa {y_n}'(\kappa)]^2}, \tag{S9}$$

here j_n and y_n are the spherical Bessel functions of the order n of the first kind and the second kind respectively and the prime denotes the derivative for each function. The parameter F_n is given as follows:

$$F_n = \frac{{\kappa_2}^2\rho_f}{2\rho_p}\cdot\frac{\dfrac{\kappa_1 j_n'(\kappa_1)}{\kappa_1 j_n'(\kappa_1)-j_n(\kappa_1)}-\dfrac{2n(n+1)j_n(\kappa_2)}{(n+2)(n-1)j_n(\kappa_2)+{\kappa_2}^2 j_n''(\kappa_2)}}{\dfrac{{\kappa_1}^2[\sigma/(1-2\sigma)j_n(\kappa_1)-j_n''(\kappa_1)]}{\kappa_1 j_n'(\kappa_1)-j_n(\kappa_1)}-\dfrac{2n(n+1)[j_n(\kappa_2)-\kappa_2 j_n'(\kappa_2)]}{(n+2)(n-1)j_n(\kappa_2)+{\kappa_2}^2 j_n''(\kappa_2)}}, \tag{S10}$$

where κ_1 and κ_2 are expressed as:

$$\kappa_1 = \frac{\pi d_p f}{c_{long}}, \tag{S11}$$

$$\kappa_2 = \frac{\pi d_p f}{c_{shear}}, \tag{S12}$$

where d_p is the particle diameter, f is the frequency, c_{long} is the longitudinal sound speed in the particle, c_{shear} is the shear sound speed in the particle. Poisson ratio of the particle (σ) in eqn (S10) is defined as:

$$\sigma = \frac{\dfrac{{c_{long}}^2}{{c_{shear}}^2}-2}{\dfrac{2{c_{long}}^2}{{c_{shear}}^2}-2}, \tag{S13}$$

Above eqns are calculated as functions of particle diameter (d_p) under the frequency of 19.32 MHz.

Table S1. List of parameters used for theoretical models.

Property	Symbol	Value
Dynamic viscosity (water)	μ	1.005e-03 Pa·s
Density (water)	ρ_f	998 kg/m^3
Density (polystyrene)	ρ_p	1050 kg/m^3
Speed of the sound (water)	c_f	1485 m/s
Speed of the sound (polystyrene)	c_p	1700 m/s
Longitudinal speed of the sound (polystyrene)	c_{long}	2350 m/s
Shear speed of the sound (polystyrene)	c_{shear}	1120 m/s

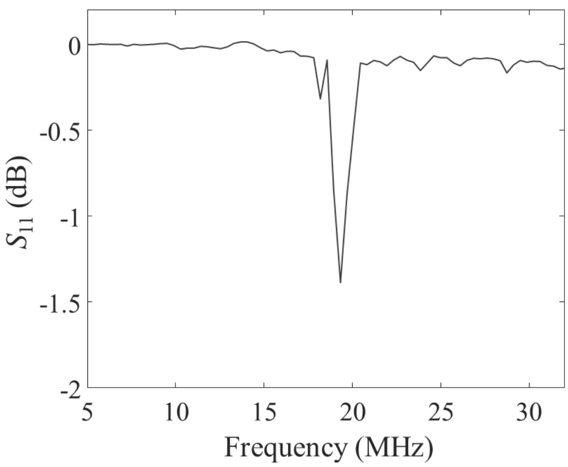

Fig. S1 S_{11} obtained from nominal frequency of 20 MHz denotes actual frequency of 19.32 MHz.

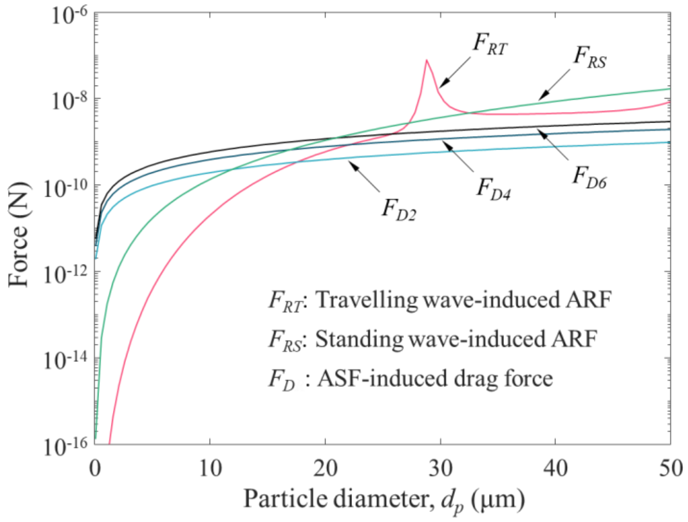

Fig. S2 Plots of time-averaged ARFs induced by travelling waves (F_{RT}) and standing waves (F_{RS}) and drag forces induced by ASF (F_D) versus PS particle size. F_D values were calculated with three different flow velocities (labeled F_{D2} for 2 mm/s, F_{D4} for 4 mm/s, and F_{D6} for 6 mm/s) based on the azimuthal velocities inside the sessile droplet. F_{RS} and F_{RT} were calculated using an E_{ac} value of about 9.78 J/m^3, with $sin(2kx)$ of 1. The remaining properties are specified in Table S1.

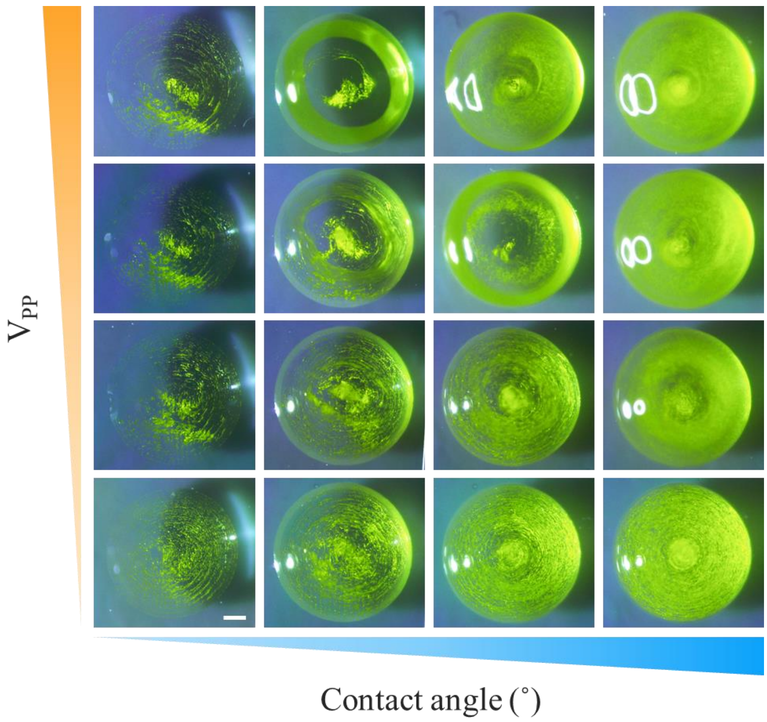

Fig. S3 Particles behaviour in a sessile droplet with different contact angles and peak-to-peak voltages. Micrographs of 10 μm PS particles in the sessile droplet were captured 10s after the SAWs were applied (Scale bar: 500 μm). SAWs were applied at the right lower side of each sessile droplet.

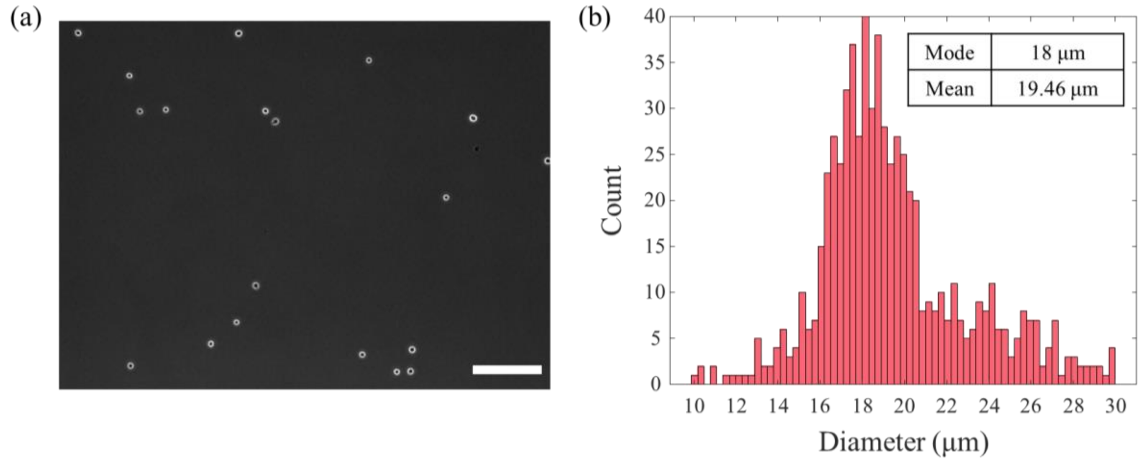

Fig. S4 MCF7 size distribution in suspension. (a) MCF7 stained by trypan blue (scale bar: 200 µm). (b) Distribution of the cell diameter.

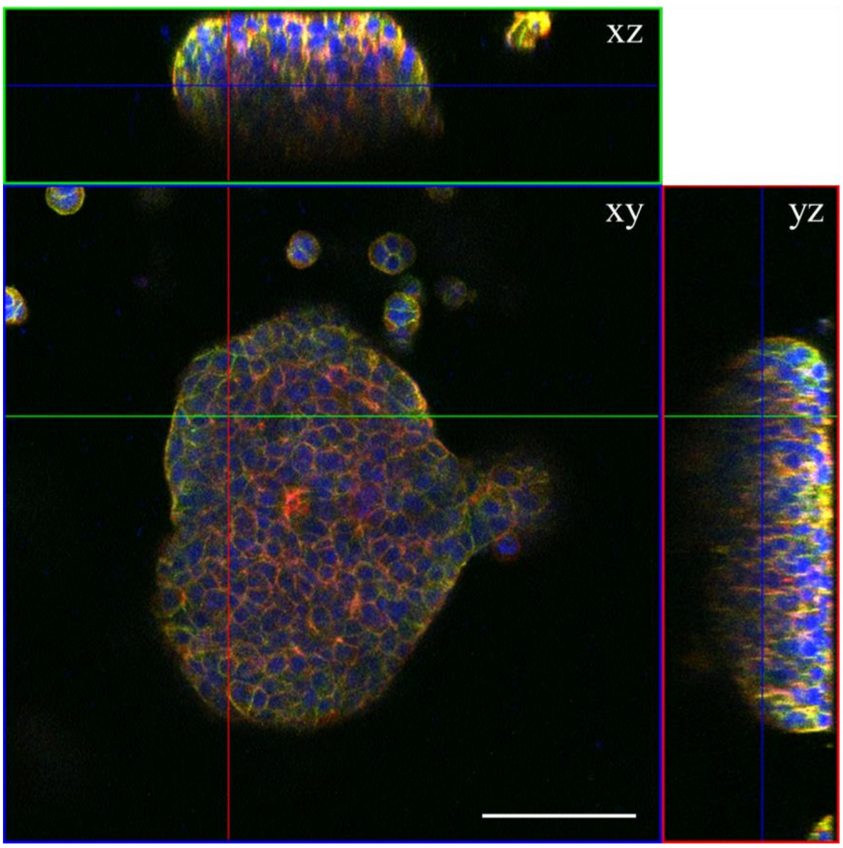

Fig. S5 Confocal orthogonal projections of patterned MCF7 (blue: nucleus, red: F-actin, green: E-cadherin, scale bar: 100 µm).

References

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