Supplementary material:

Reparable Cell Sonoporation in Suspension: Theranostic Potential of Microbubble

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Supplementary Figures

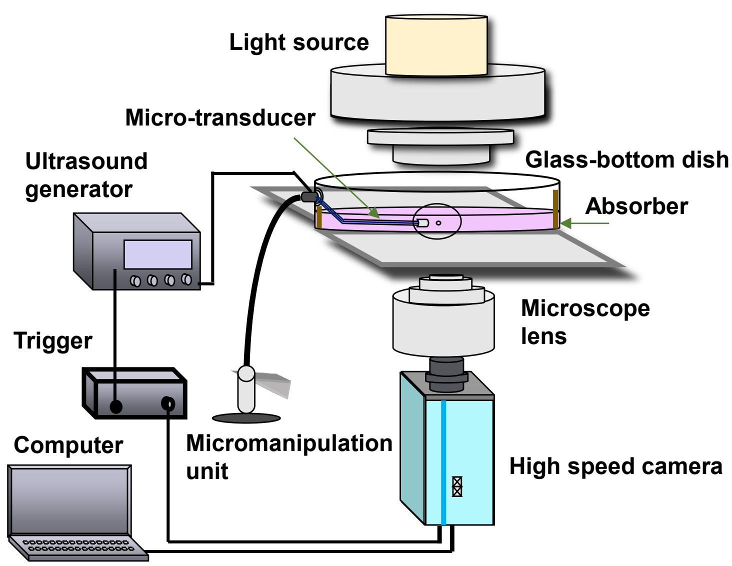

Figure S1: A schematic diagram of the experimental set up.

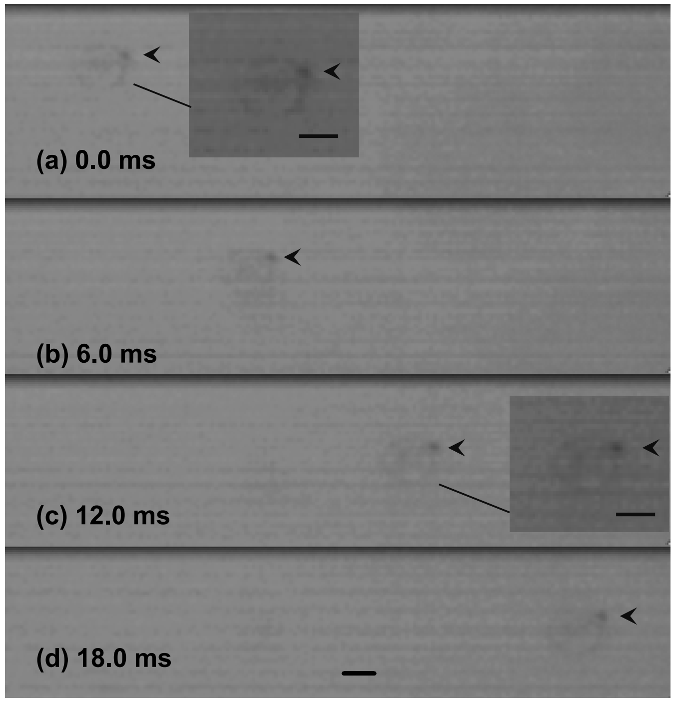

Figure S2: High-speed real-time images of a U937 cell with an 1.25 μm-radius Sonazoid microbubble attached to its membrane (arrowed) and exposed to US (0.12 MPa at 0.834 MHz) from left side of the images. Time in milliseconds relative to the first frame is indicated on each frame. Magnified images of frames (a) and (c) are shown (refer to the online file for higher magnification). (Scale bars: 10 μm)

Equations and Analysis

Under linear approximation for small amplitude oscillations ($r_{(t)}=r_0+\varepsilon_{(t)}$, $|\varepsilon_{(t)}|\ll r_0$) of modified Rayleigh-Plesset equation near a rigid wall, the bubble oscillation amplitude ε_0 can be obtained [29]:

$$\varepsilon_0 = \frac{p_{ac}}{\rho r_0 \omega_0^2 \left(1+\frac{r_0}{2D}\right)} \left[(1-\Omega^2)^2 + \Omega^2 \frac{\delta^2}{\omega_0^2} \right]^{-1/2}, \quad \text{(S1)}$$

where r_0 is bubble initial radius, D is distance between the bubble and the cell wall (Fig. 1a), ρ is density of the medium, P_{ac} is acoustic pressure amplitude; δ represents the shell friction and elasticity parameters, $\Omega=\omega/\omega_0$, ω is angular frequency, and ω_0 is natural angular frequency of the encapsulated bubble near the wall:

$$\delta = \frac{1}{\left(1+\frac{r_0}{2D}\right)} \left(\frac{4\mu}{\rho r_0^2} + \frac{4\kappa_s}{\rho r_0^3} \right); \quad \omega_0 = \left\{ \frac{1}{\left(1+\frac{r_0}{2D}\right)} \left[\frac{3k}{\rho r_0^2} \left(P_0 + \frac{2\sigma}{r_0} \right) - \frac{2\sigma}{\rho r_0^3} + \frac{2S_p}{\rho r_0^3} \right] \right\}^{1/2}, \quad \text{(S2)}$$

$S_p=2x=2(3G_s\,\varepsilon_{lipid})$ and ($\kappa_s=3\mu_{lipid}\varepsilon_{lipid}$) represent shell elasticity and friction parameters.

The cell medium's physical properties of $\rho=10^3$ kg.m^{-3}, dynamic viscosity $\mu=1.05\times10^{-3}$ Pa.s, and surface tension $\sigma=0.072$ N.m^{-1} (at 20°C experimental condition), atmospheric pressure P_0=101 kPa, and Sonazoid encapsulated microbubble's lipid-stabilized shell properties of shear modulus G_s=52 MPa [32], viscosity μ_{lipid}=0.99 Pa.s, and shell thickness $\varepsilon_{lipid(av)}$=2.5 nm [21], containing perfluorobutane (C_4F_{10}) gas with polytropic exponent k=1.07, under acoustic pressure amplitude P_{ac}=0.12 MPa and frequency f=0.834 MHz of the insonation protocol, were used to calculate natural frequency and oscillation amplitude of the microbubble (r_0=1.25 μm).