Supporting Information

Ultralong-time recovery and low-voltage electroporation for biological cell monitoring enabled by a microsized multi-pulse framework

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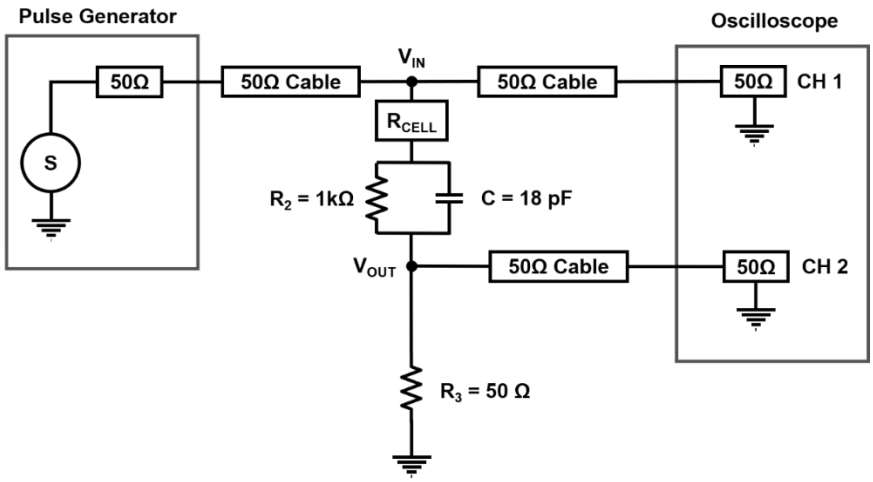

Figure S1. Schematic of testing setup for cell electroporation.

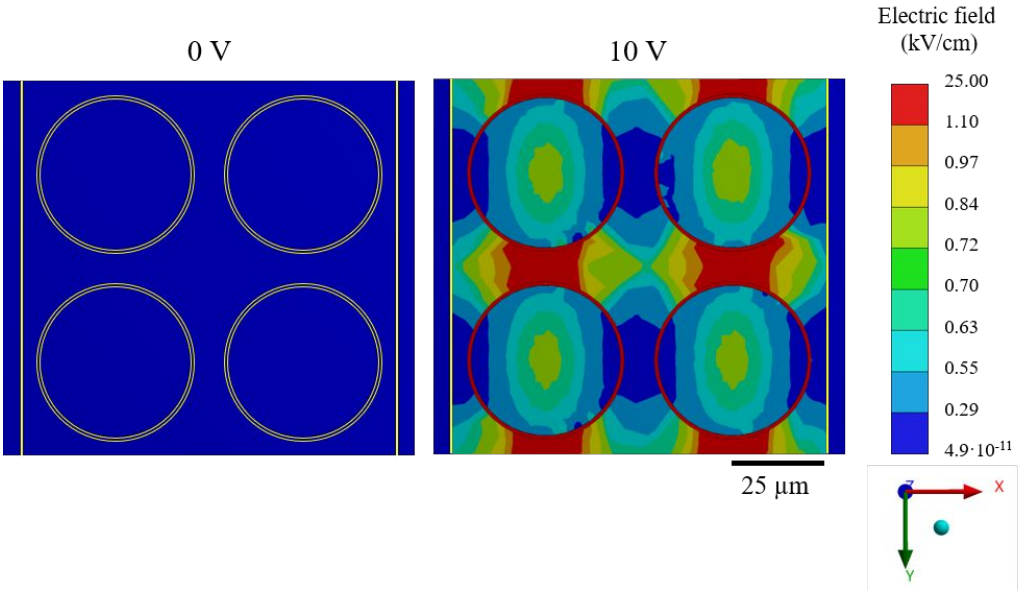

Figure S2. Electric field distribution of four cells with no excitation (left panel) and with ~10 V rectangular-pulse excitation (right panel). The simulation was performed with a ~10 V, ~1 µs square-wave single-pulse.

Table S1. Parameters used for finite element simulations.

Parameters	Values
Conductivity of ITO	1.3×10^{4} S/cm
Conductivity of cell	4.44×10^{-3} S/cm
Size of gap	0.1 mm
Voltage	10 V

Table S2. Raw impedance values of MCF-7 cells over a period of 0 – 120 min with different number of bias-voltage pulses.

	Measured impedance over time (Ω)					
Number of pulses	**0 min**	**5 min**	**10 min**	**15 min**	**60 min**	**120 min**
0	1.33E+03	1.18E+03	1.12E+03	1.04E+03	9.77E+02	7.69E+02
10	1.31E+03	1.17E+03	1.10E+03	1.00E+03	7.78E+02	7.13E+02
50	1.31E+03	1.20E+03	1.17E+03	1.09E+03	9.51E+02	8.13E+02
100	1.31E+03	1.17E+03	1.17E+03	1.14E+03	1.07E+03	1.02E+03
150	1.29E+03	1.26E+03	1.26E+03	1.26E+03	1.26E+03	1.19E+03
200	1.33E+03	1.26E+03	1.31E+03	1.28E+03	1.31E+03	1.30E+03

Table S3. Comparison of state-of-the-art electroporation systems.

Paper	Cell type	Type of electroporation	Pulse number	Pulse width	Gap distance	Field strength	Time of recovery
Int. J. Cancer **121,** 675–682 (2007) [69]	4T1 cells	Cell population	80 at 1 Hz	100 µs	4 mm	600 V/cm, 700 V/cm	No info
Biophys. J. **84,** 2709–2714 (2003) [51]	Jurkat cells	Cell population	1	60 ns, 300 ns, 10 ms, and 100 ms	0.33 mm	3–150 kV/cm	No info
PLoS One **7,** e51349 (2012) [70]	N1-S1 cells	Cell population	1	600 ns – 15 ns or 150 ns rise time	10 mm	0-80 kV/cm	No info
Bioelectromagnetics **33,** 257–264 (2012) [71]	Human Jurkat T lymphocytes	Cell population	5 for 100 µs and 10 for 30 ns, 4 Hz	100 µs, 30 ns	1 mm	0.5 MV/cm 2.5 MV/cm	No info
Cancer Res. **72,** 1336–1341 (2012) [72]	DC-3F, K-562, Lewis Lung Carcinoma	Cell population	8 at 1 Hz	99 µs	4 mm	1.2 – 1.4 kV/cm	No info
Int. J. Cancer 121, 675–682 (2007) [73]	Jurkat and RPMI 8226 cells	Cell population	200, 300 or 500, 20 Hz	20 ns	1 mm	35 kV/cm	No info
Bioelectrochemistry **57,** 167–172 (2002) [74]	DC3F cells	Cell population	1, 10, 1000, 2500	100 µs, 30 µs	2 mm	-	No info
Technol. Cancer Res. Treat. **17,** 1–15 (2018) [55]	CHO-K1 cells	Cell population	1	10 µs, 100 µs, 1000 µs	2, 4, 6, and 8 mm	170, 250, 320, and 400 kV/m	No info
J. Membr. Biol. **245**, 617–624 (2012) [49]	C2C12 and HEK 293 cells	Cell population	8	100 µs	0.150 mm	1.2, 1.6, 2 and 2.2 kV/cm	30 min
This work	**MCF-7 cells**	**Cell population**	**10, 50, 100, 150 and 200 pulses**	**1 µs**	**0.1 mm**	**250, 350 and 500 V/cm**	**120 min**

Table S4. Raw impedance values of MCF-7 cells when electroporated using 200 pulses with different voltage amplitudes.

Bias voltage (V)	Measured impedance (Ω)
0	2.65E+03
2.5	1.62E+03
3.5	2.11E+03
5.0	1.64E+03