Electronic supplementary information (ESI)

Collaborative effects of electric field and fluid shear stress on fibroblast migration

Sukhyun Song, Hana Han, Ung Hyun Ko, Jaemin Kim and Jennifer H. Shin*

Division of Mechanical Engineering, School of Mechanical, Aerospace and Systems Engineering,

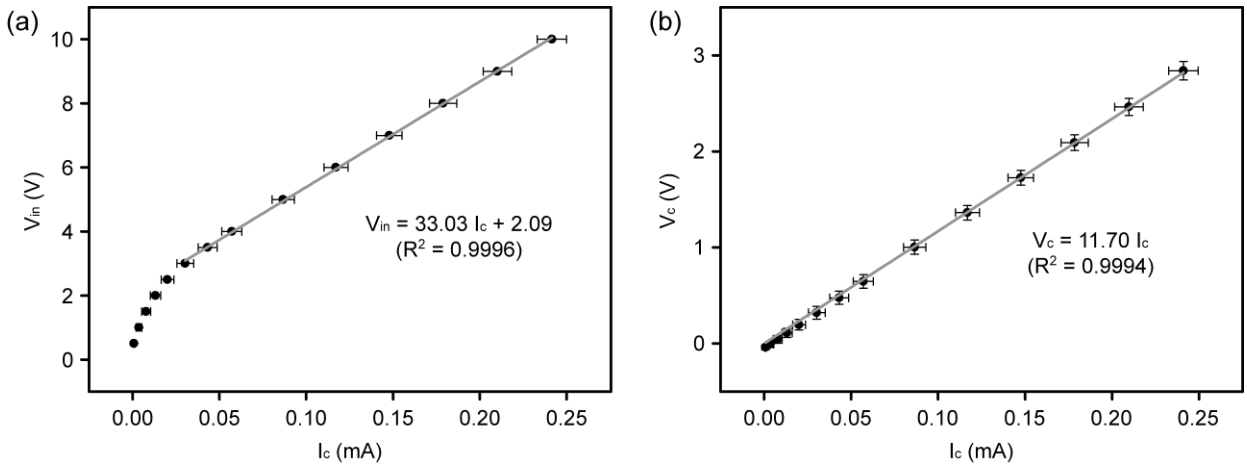
Korea Advanced Institute of Science and Technology,

291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea.

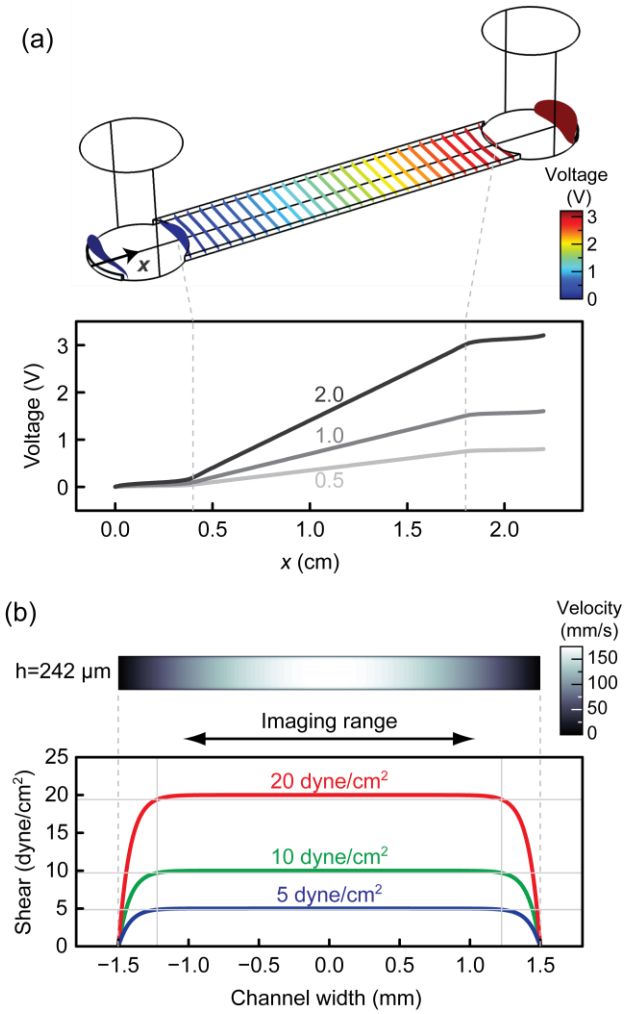
Fax: +82-42-350-3210;

Tel: +82-42-350-3232;

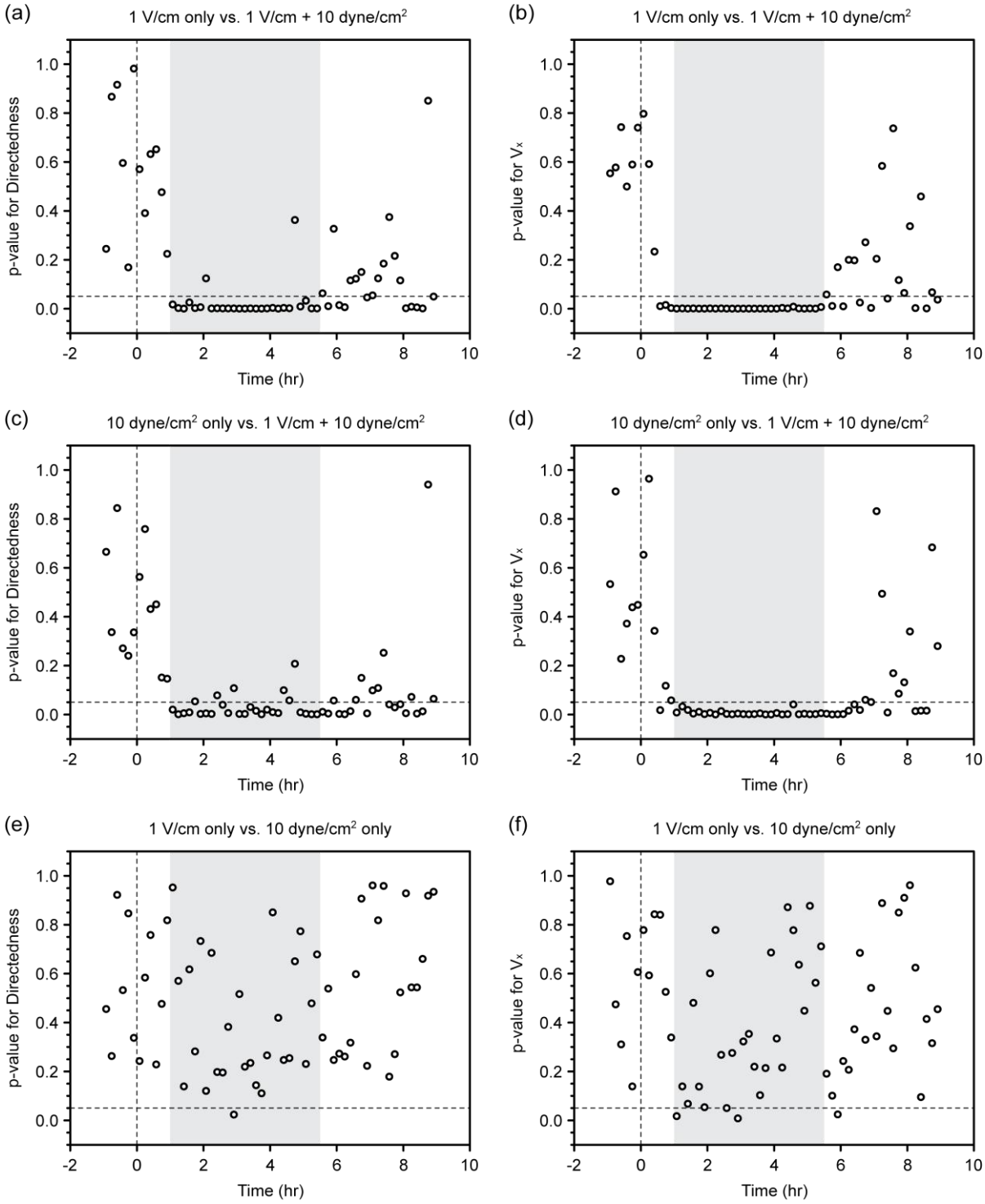
E-mail: j_shin@kaist.ac.kr



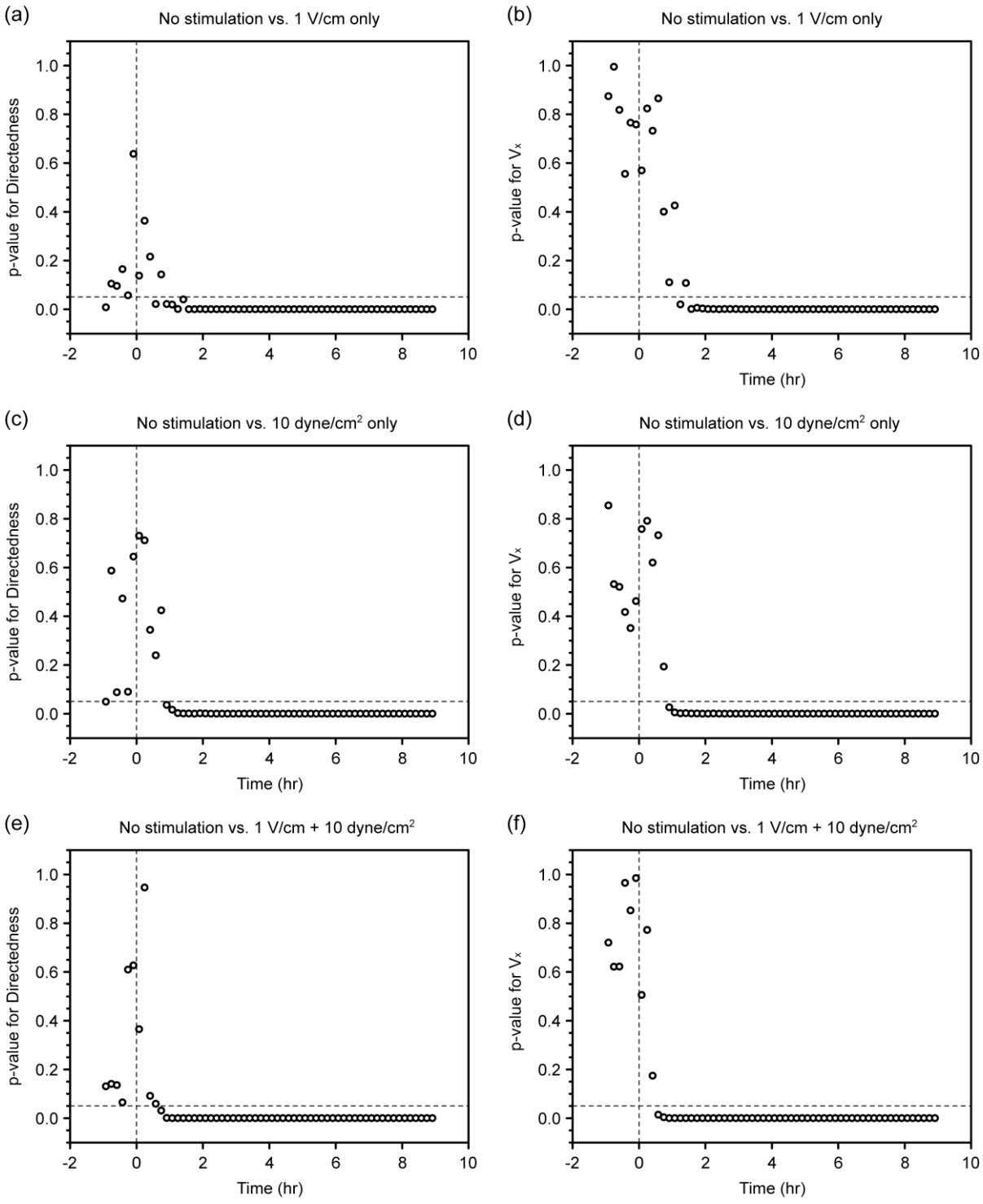
Supplementary Fig. S1 Voltage-current characteristics of the microfluidic channel. (a) Input voltage (V_{in}) driven by the voltage source varied from 0.50 to 10.0 V. Channel voltage (V_c) is directly measured by voltage probe at the inlet and outlet of the cell culture channel filled with culture media, and channel current (I_c) is measured by a portable ampere meter (Agilent Technologies Inc., CA, USA). Because the voltage source and various resistance components are connected in series as a single-loop electrical circuit, the current passing through the circuit is common. A linear relationship between input voltage (V_{in}) and channel current (I_c) was observed in the range of 3 to 10 V of V_{in}, which fully covers our experimental range of 0.5 to 2 V/cm of electric field. The nonlinear relationship in the low current regime can be explained by the electric properties of the porous embedded agar salt bridges. (b) Because channel voltage (V_c) is directly proportional to the channel current (I_c), the cell culture channel can be regarded as a linear resistor (R=11.70 kΩ), which is represented by the slope in the voltage-current plot. From the geometry of the channel, electrical resistivity ($\rho=R\cdot A/\ell$) of the culture media was 0.202 Ω·m, where A is the cross-sectional area and ℓ is the length of the channel. This obtained electrical resistivity value was utilized in the electric field simulation as shown in Supplementary Fig. S2 (a). Voltage-current characteristics were measured in five independent channels, and error bars represent the standard error of the mean.



Supplementary Fig. S2 Simulation for the distribution of electric field (EF) and shear stress in the microchannel. (a) The equipotential surfaces, illustrated by a color spectrum, are perpendicular to the channel length direction (x) as the electric potential linearly increases along the center line (x) of the channel. Therefore, EF is constant inside the cell culture channel. (b) Fluid velocity inside the channel is calculated from an exact solution and depicted as gray scale for the 20 dyne/cm^2 shear stress condition in the upper panel. Wall shear stress at the bottom surface with respect to the channel width is shown in the lower panel. The central 81.6% range is exposed to constant shear stress with less than 3% difference from the maximum shear stress at the center of channel. This uniform shear region fully covers the imaging range (approximately 2 mm in width) when using a 5× objective lens.



Supplementary Fig. S3 Statistical significance of instantaneous directedness and instantaneous velocity parallel to the direction of stimulation (V_x) of the collaborative migration in Fig. 3 (c, d). The p-value between two different conditions at each time point was obtained from a two-sample t-test at 5% significance level by MATLAB (MathWorks Inc., MA, USA). Stimulation was applied at t=0. Criteria of p=0.05 is depicted as a horizontal dotted line and shaded boxes show time ranges from 1 to 5.5 hours of stimulation.



Supplementary Fig. S4 Statistical significance of instantaneous directedness and instantaneous velocity parallel to the direction of stimulation (V_x) in response to single or simultaneous stimulation compared with no stimulation in Fig. 3 (c, d). The p-value between two different conditions at each time point was obtained from a two-sample t-test at a 5% significance level by MATLAB (MathWorks Inc., MA, USA). Stimulation was applied at t=0. Criteria of p=0.05 is depicted as a horizontal dotted line.

Supplementary Video S1

Normal human dermal fibroblast (NHDF) migration behavior for 9 hours in response to simultaneous stimulations of 1 V/cm electric field (anode on the right side) and 10 dyne/cm^2 shear stress (flow direction from the left to right side) (scale bar: 200μm)

Supplementary Video S2

NHDF migration behavior for 9 hours in response to 1 V/cm electric field (anode on the right side) (scale bar: 200μm)

Supplementary Video S3

NHDF migration behavior for 9 hours in response to 10 dyne/cm^2 shear stress (flow direction from the left to right side) (scale bar: 200μm)

Supplementary Video S4

NHDF migration behavior for 9 hours without stimulation (scale bar: 200μm)

Supplementary Video S5

NHDF migration behavior for 18 hours in response to sequential stimulation of 1 V/cm electric field (anode on the right side) and 10 dyne/cm^2 shear stress (flow direction from the left to right side) (scale bar: 200μm)