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Supplementary Information for

All-electrical monitoring of bacterial antibiotic susceptibility in a microfluidic device

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Supporting Information Text

Supplemental Materials and Methods

Device Design and Fabrication. In designing the device, we used a first-pass optimization to determine the number k of parallel microchannels. The throughput increases (and the loading time decreases) with increasing k. However, the available signal from a microchannel is divided between k parallel resistors (see the resistance change calculation due to a single bacterium below). The use of $k = 10$ parallel microchannels allowed us to achieve a loading time $\lesssim 30$ min and to comfortably observe resistance changes due to single cells.

Molds for the two-layer microfluidic channel are fabricated by patterning SU-8 photoresist (Microchem, Newton, MA) onto a 4-inch silicon wafer. After mixing pre-polymer with cross-linker (Sylgard 184, Dow Corning, Midland, MI) at a 9:1 ratio, the mixture is degassed in a vacuum desiccator for 30 minutes. Next, the bubble free PDMS mixture is slowly poured onto the SU-8 mold and cured in a 90°C oven for 1 hour. The slab of PDMS with the embedded two-layer microfluidic channel structure is carefully peeled off from the master. Inlet and outlet ports (0.75 mm diameter) are mechanically punched into the PDMS using a biopsy punch. The PDMS structure and a glass slide with pre-defined metallic electrodes are sterilized and bonded through oxygen plasma treatment. To fabricate the chromium (Cr) and gold (Au) electrodes onto the glass slide, we use electron beam evaporation. The electrodes are fabricated by evaporating a 90-nm-thick Au layer on top of a 60-nm-thick Cr adhesion layer.

Bacteria Culturing. First, lyophilized bacteria are re-solubilized and mixed gently with 1 mL of LB broth, and the solution is transferred into 5 mL of LB broth for each bacterial strain. Next, the bacteria are grown in a shaking incubator at 37°C and 100 rpm for 24 hours. After 24 hours, the turbid bacterial suspension is centrifuged for 6 minutes at 6000 rpm, and the bacteria pellet is re-suspended in 5 mL of fresh LB broth. Finally, frozen stocks are prepared by dissolving highly purified glycerol (MP Biomedicals, Solon, OH) at 20% v/v in PBS (Lonza BioWhittaker, Walkersville, MD), mixing with bacterial suspension at 1:1 ratio, collecting into 200 μL aliquots and storing at -80°C. On the day prior to the experiment, a frozen stock is thawed, of which 150 μL is transferred into 8 mL of fresh LB broth; 10 μL of the bacterial culture is streaked on a LB agar (Becton Dickinson, Sparks Glencoe, MD) plate and grown overnight to check the purity of the bacterial culture. Bacteria are cultured overnight at 37°C in a shaking incubator at 100 rpm. On the day of the experiment, the bacteria culture is diluted to the desired concentration. We measure the optical density of the culture at a wavelength of 600 nm (OD_{600}) using a spectrophotometer (V-1200, VWR, Radnor, PA). An OD_{600} of 0.1 corresponds to a bacterial cell density of 2×10^7 CFU/mL, which is periodically confirmed through serial dilution plating on LB agar plates.

Resazurin-Based Broth Microdilution AST. In order to compare our method with standard methods, the susceptibility of *E. coli*, *K. pneumoniae*, and *S. saprophyticus* are determined using resazurin-based broth miltidilution AST standardized by the Clinical and Laboratory Standard Institute (CLSI). To ensure consistency, *E. coli* (ATCC 25922), for which the MICs of both ampicilin and nalidixic acid are 4 mg/L (1), is used as a reference strain for all the resazurin-based microdilution tests. First, ampicillin and nalidixic acid are diluted from stock solutions in LB broth. Column 12 of the 96-well plate is used as growth control (no antibiotics); column 11 is used as sterility control (no bacteria); and columns 1-10 are filled with solutions with decreasing antibiotic concentrations, which are prepared by using the two-fold serial dilution method. Next, the bacterial cultures are prepared separately at 37°C in 8 mL of LB broth. After adjusting their OD_{600} to 0.1, the solution is further diluted by a factor of 20 with LB broth. Then, 100 μL of bacteria solution is added to each well of columns 1 to 10, and column 12. The final bacterial concentration in each well is 5×10^5 CFU/mL. The bacterial suspensions are used within 30 min after their optical density are adjusted to avoid changes of cell numbers (2). Each concentration is replicated in three wells in each plate. After incubating the plate at 37°C in a shaking incubator at 100 rpm for 16-20 hours, 60 μL 0.015% solution of resazurin (ACROS Organics, New Jersey, USA) in tissue culture grade water is added to each well and further incubated at 37°C for another 4 hours. The plate results are read by visual inspection of the wells. Dark blue/purple indicates that bacteria are not viable, and pink indicates that bacteria are still viable. If the growth control shows dark blue/purple or the sterility control indicates contamination, the plate is discarded. The MICs determined using the resazurin-based broth miltidilution AST are summarized in Table S1.

Experimental Protocol for Electrical Measurements. We measure the growth of *E. coli*, *K. pneumoniae*, and *S. saprophyticus* in LB broth with and without antibiotics. After adjusting an overnight bacterial culture to an OD_{600} of 0.1, the culture is diluted 1:20 into 5 mL LB broth and, depending on the experiment, mixed with antibiotics in equal volume. This results in a final bacterial cell density of 5×10^5 CFU/mL. The mixture is transferred into a sterile 15-mL Falcon tube that is used as a sample reservoir. A fluorinated ethylene propylene (FEP) tube (Cole-Parmer, Vernon Hills, IL) is used to connect the sample reservoir to the microfluidic device inlet. During sample loading, the inlet is pressurized at $\Delta p \sim 10$ kPa above the outlet. The number of trapped bacteria is typically not uniform across microchannels. After approximately tens of bacteria are trapped in the microchanels, voltage drop across the microchannels is measured to quantify the bacterial growth. During the measurements, the pressure difference between inlet and outlet is maintained at $\Delta p \sim 0.5$ kPa. The pressure during loading is controlled using a pressure controller (OB1-Mk3, Elveflow, Paris, France). To ensure a stable temperature of the microfluidic device during an experiment, a PeCon 2000–2 Temp Controller (PeCon GmbH, Erbach, Germany) is used. To show that our microfluidic device can be used to determine MICs for antibiotics in human urine samples, we measure *K. pneumoniae* in nalidixic acid and *E. coli* (non-motile) in ampicillin. Bacteria concentration is adjusted to an OD_{600} of 0.1, and the bacteria solution is diluted 1:20 in 5

mL of human urine sample. Subsequently, the bacteria-spiked urine samples are mixed with LB broth and nalidixic acid (0, 4, 8, 16, and 32 mg/L) or ampicillin (0, 2, 4, 8, and 16 mg/L) in equal volume prior to loading into a microfluidic device.

Electrical Measurements. Fig. S1 shows the simplified equivalent circuit model of the electrical measurement. The lock-in amplifier oscillator output V_s (rms amplitude of 1 V and reference frequency of $f_r = 10$ Hz) is connected to a resistor $R_s = 100$ MΩ to create a current source, which drives a current (several nA) through the device and the input circuit of the lock-in. The input resistance of the lock-in amplifier is 10 MΩ. We use a four-wire measurement to measure the resistance of the device. At $f_r = 10$ Hz, the four-wire electrical impedance of the device is dominated by its resistance; typical device impedance at the start of each experiment is $\approx 3 - 0.2i$ MΩ, corresponding to a phase angle of -4°. The resistance value and the phase both drift over the course of two hours. The drift in the resistance is $\lesssim 1\%$ and the impedance phase angle is $\pm 1^{\circ}$. We estimate each contact impedance to be $\approx 70 - 700i$ kΩ at 10 Hz through two-wire measurements. We use a 300 ms time constant on the lock-in amplifier and digitally sample the data from the lock-in at a rate of 6 Hz. When we focus on the long-term behavior of the resistance (e.g., growth or antibiotic susceptibility measurements over two hours), we further integrate (average) the data numerically over one-minute intervals. When we focus on the short-time fluctuations (i.e., Fig. 4 in main text), we high-pass filter the data using a cut-off frequency of 0.01 Hz.

The time-dependent resistance of the device can be expressed as $R(t) = R_{em} + \Delta R(t)$, where R_{em} is the initial resistance of the microchannels with pure LB broth and $\Delta R(t)$ is the resistance change induced by bacteria in the microchannels. We can estimate the minimum detectable ΔR from noise analysis. In the experiments, the equivalent noise bandwidth at a time constant of 300 ms is $\Delta f \approx 0.31$ Hz (time constant 300 ms and filter roll-of 18 dB/oct). To determine the experimental noise floor, we perform a noise measurement using a 3.2 MΩ source resistor. We obtain a total noise of ~ 600 nV/Hz$^{1/2}$. This value is slightly larger than the theoretical value of ~ 300 nV/Hz$^{1/2}$, obtained from combining the Johnson noise of a 3.2 MΩ resistor (230 nV/Hz$^{1/2}$) with the input noise, $V_n^{(a)}$, of the lock-in at 10 Hz ($V_n^{(a)} \lesssim 200$ nV/Hz$^{1/2}$). We use a low-sensitivity setting on the lock-in to be able to track the large changes in the device resistance during bacteria growth. The minimum detectable resistance change or the resistance noise can be estimated from a simple circuit analysis. Here, we assume that the minimum detectable resistance change (under the imposed current of 10 nA across the device and the lock-in input) results in a voltage equal to the noise voltage. This provides ≈ 200 Ω, which is close to the resistance fluctuations (noise) observed in LB broth.

In order to quantify the effect of the long-term electrical drifts on the sensitivity, we have performed a set of experiments using devices clogged with 1-μm-diameter polystyrene (PS) microspheres. This is similar to clogging the microchannels with bacteria but, since the PS microspheres do not change in size over time, we are able to extract the electrical drift under conditions comparable to bacteria experiments. In particular, we clog the devices to resistance values $R(0)$ (or $\Delta R(0)$) close to those in bacteria experiments, indicating similar flow rates and initial conditions. Three baseline resistance drifts measured over the course of 2 hours are shown in Fig. S2*A*. Since the drift appears linear, we fit it as $\Delta R(t) - \Delta R(0) \approx -0.26t$ (in units of kΩ when t is in minutes). In an effort to quantify the drift effect on the antibiotic susceptibility tests, we have recalculated the drift-corrected growth rates (dashed lines in Fig. S2*B-F*). Here, the solid lines are the results from Fig. 3 in the main text. In the recalculation, we first subtracted the drift from each data trace and then computed the growth rate. Our conclusion, after comparing the growth rates of corrected and raw data in Table S2, is that drift can safely be neglected at this stage of development.

Resistance Change Per Added Bacterium. We show the resistance change ΔR as a function of the number n of bacteria in the microchannels for *K. pneumoniae*, *E. coli*, and *S. saprophyticus* in Fig. S3. Data shown in each figure are from three independent experiments. Red dashed lines are the linear fits to the data. We obtain $\Delta R_1^{(KP)} \approx 2.5 \pm 0.3$ kΩ for *K. pneumoniae* (Fig. S3*A*), $\Delta R_1^{(EC)} \approx 3.7 \pm 0.3$ kΩ for *E. coli* (Fig. S3*B*), and $\Delta R_1^{(SS)} \approx 3.5 \pm 1.1$ kΩ per *S. saprophyticus* (Fig. S3*C*). The larger error in *S. saprophyticus* originates from the fact that it is more challenging to count single cells from microscope images and cells tend to cluster more.

The measured R_{em} is the equivalent resistance of ten parallel microchannels at the center of the microfluidic device: $R_{em} = \frac{1}{10} R_{em}^{(s)}$, where $R_{em}^{(s)}$ is the single microchannel resistance, $R_{em}^{(s)} = \rho \frac{l}{A}$, with ρ being the electrical resistivity of the liquid media (e.g., LB broth) filling the microchannel, l and A being respectively the length and cross-sectional area of the single microchannel. We assume that the electrical resistance of bacteria is large compared to the media. Thus, the resistance of a single microchannel with one trapped bacterium can be estimated as $R_{em}^{(s)} + \Delta R_1^{(s)} \approx \rho \left[\frac{l - l_B}{A} + \frac{l_B}{A - A_B} \right]$, where l_B and A_B are the length and cross-sectional area of a bacterium, respectively. Here, $R_{em} \approx 3$ MΩ in LB broth, which, using the nominal channel dimensions, gives $\rho \approx 1.2\ \Omega \cdot$ m. *K. pneumoniae* is rod-shaped, with $l_B = 2$ μm and $A_B = 0.8$ μm^2 (3). Using these numbers, we obtain $\Delta R_1^{(s)} \approx 150$ kΩ. Calculating the equivalent resistance, we find the total resistance change per bacterium becomes $\Delta R_1 \approx \frac{\Delta R_1^{(s)}}{100} \approx 1.5$ kΩ. Note that the resistance change per bacterium very much depends on the size of the bacterium and how the bacterium blocks the microchannel during growth. It is thus different for *S. saprophyticus* and *E. coli*.

Bacteria Accumulation or Growth Outside of the Microchannels. We occasionally observe bacteria accumulation outside of the microchannels or growth outward. Fig. S4 shows two different non-ideal ways bacteria accumulate in the device. The linear dimensions of the regions immediately upstream and downstream from the microchannels are $l \times w \times h \approx 75 \times 80 \times 2$ μm^3. The microscope images in Fig. S4 show a portion of this region in addition to the central microchannels. Fig. S4*A* shows that bacteria (*E. coli*) can get immobilized in the inlet region; in addition, any bacteria that escapes through the nanoconstriction

can proliferate in the outlet region. Fig. S4*B* shows that bacteria (*S. saprophyticus*) can get stuck at the entry region of the microchannels, blocking further bacteria trapping in the microchannels. When bacteria are trapped in these bigger channels ($l \times w \times h \approx 75 \times 80 \times 2$ μm^3), the resistance change per added bacterium no longer follows the ideal case discussed in the main text. In fact from geometry, the resistance change per bacterium is $\sim \frac{1}{20}\Delta R_1$, where $\Delta R_1 \approx 1.5$ kΩ is the resistance change per added bacterium into one of the ten smaller microchannels, as discussed above. For bacteria accumulating outside of this 2-μm-high region, the resistance change is even smaller. Thus, our measured resistance signals mainly come from the ten smaller microchannels. We note that bacteria trapped outside the microchannels also grow (or die). Thus, their signals are coherently added to the signals developing in the microchannels. Finally, if the experiment continues for a long time, bacteria, especially motile strains, tend to escape more readily and/or grow outward after filling the microchannels.

Estimation of Bacterial Doubling Time. We have estimated the doubling time t_d of bacteria using resistance change data during growth. As discussed in the main text, $\frac{\Delta R(t)}{\Delta R(0)} \approx \frac{n(t)}{n(0)} = e^{\frac{\ln 2}{t_d}t}$. Thus, t_d can be obtained by a linear fit to the natural logarithm of $\frac{\Delta R(t)}{\Delta R(0)}$. Fig. S5 shows a number of fits (dashed lines) to the experimental resistance data (solid lines) for *E. coli*, *K. pneumoniae*, and *S. saprophyticus*. Each curve is from an independent experiment. The t_d and R^2 values are as indicated in the figure.

Data from All Measurements. Fig. S6 shows the resistance change, $\Delta R(t) - \Delta R(0) = R(t) - R(0)$, measured over the course of 2 hours after sample loading in all our antibiotic susceptibility tests and growth experiments. For each data plot, the right y axis shows the change in the number of bacteria in the device, $\Delta n(t)$, which is estimated from $\Delta n(t) = \frac{\Delta R(t) - \Delta R(0)}{\Delta R_1}$ with ΔR_1 being the calibration value from Fig. S3. The initial resistances $R(0)$ measured at the start of each electrical measurement are shown in Table S3. The approximate number of trapped bacteria in the microchannels at the start of each electrical measurement from microscope images are listed in Table S4.

Metric for Assessing Antibiotic Susceptibility. A simple metric for aility can be obtained from the time derivative of the resistance data, $\frac{d}{dt}\ln\left[\frac{\Delta R(t)}{\Delta R(0)}\right]$. Given that $\frac{\Delta R(t)}{\Delta R(0)} \approx \frac{n(t)}{n(0)}$ and $n(t) \approx n(0)e^{rt}$, $\frac{d}{dt}\ln\left[\frac{\Delta R(t)}{\Delta R(0)}\right] \approx r$. If $r > 0$, the population grows; if $r \leq 0$, the population does *not* grow. Since r itself is a function of time, especially for antibiotics acting with some delay, it may be more appropriate to consider r averaged over roughly the second half of the experiment. Thus, we calculate $\bar{r}$ averaged over the last 40 mins of available data, which corresponds to the last 60 mins of the resistance measurement due to the 20-min time window of the derivative. Table S2 shows $\bar{r}$ values in all experiments calculated from raw data as well as drift-corrected data (Fig. S2*B-F*). This metric provides conclusions consistent with standard AST results. We note, however, that $\bar{r} \leq 0$ may be too restrictive a condition for susceptibility, especially for a clinical application. More data and error analysis may allow us to relax this condition to $\bar{r} \leq \varepsilon$, where $\varepsilon > 0$.

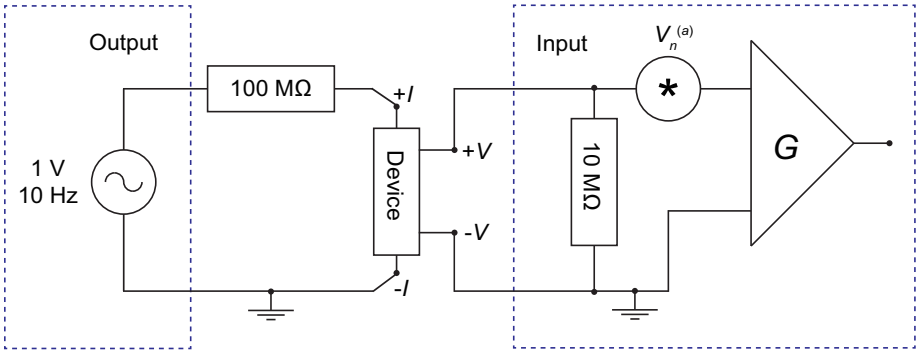

Fig. S1. Equivalent-electrical circuit for the measurement. The dashed boxes represent the lock-in amplifier; $V_n^{(a)}$ is the input noise voltage and G is the gain of the lock-in amplifier.

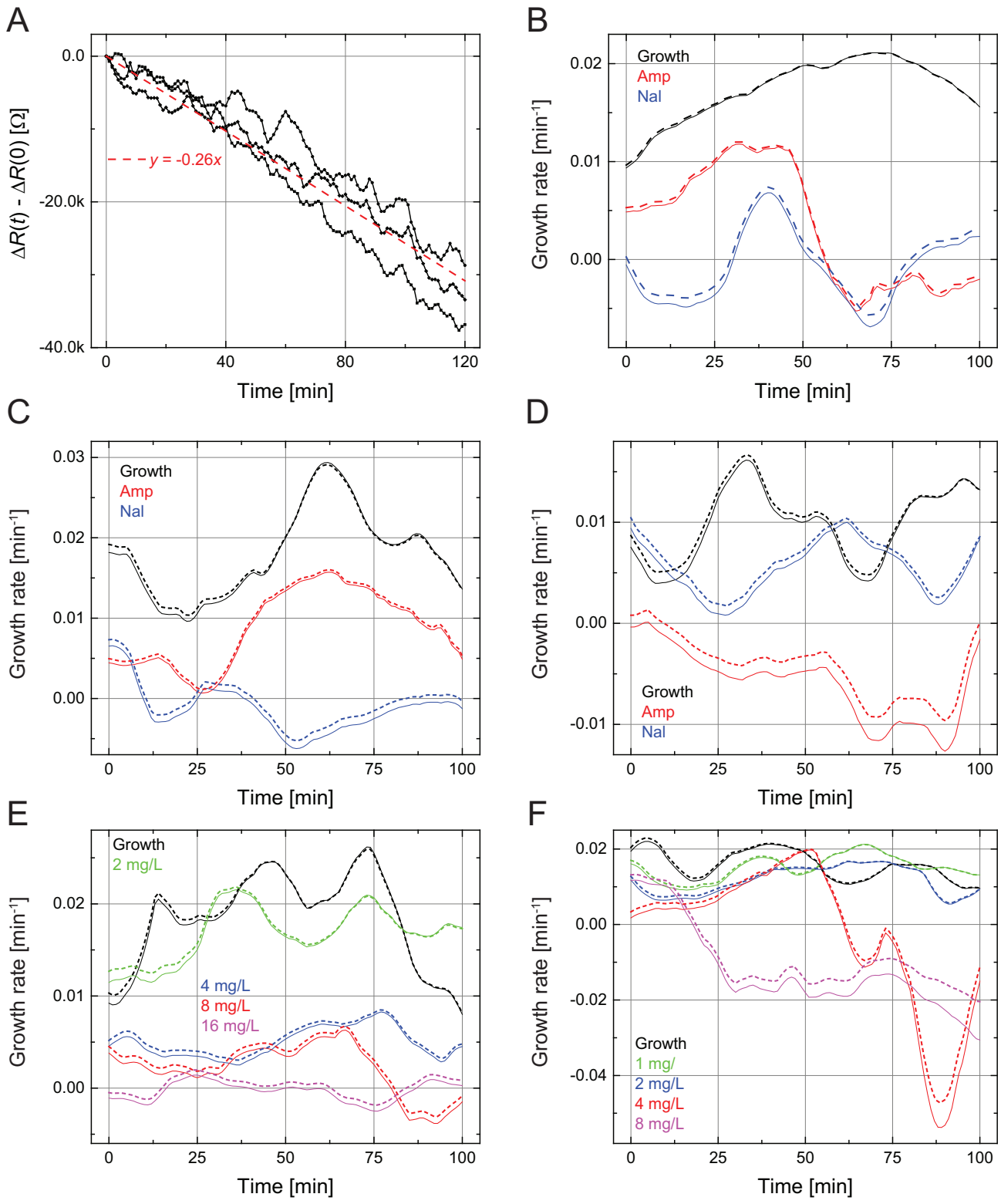

Fig. S2. (*A*) Baseline drifts as a function of time in three independent experiments; the red dashed line shows the linear fit. (*B-F*) Growth rates from raw (solid lines) and drift-corrected resistance data (dashed lines). Solid lines are reproduced from Fig. 3 in the main text.

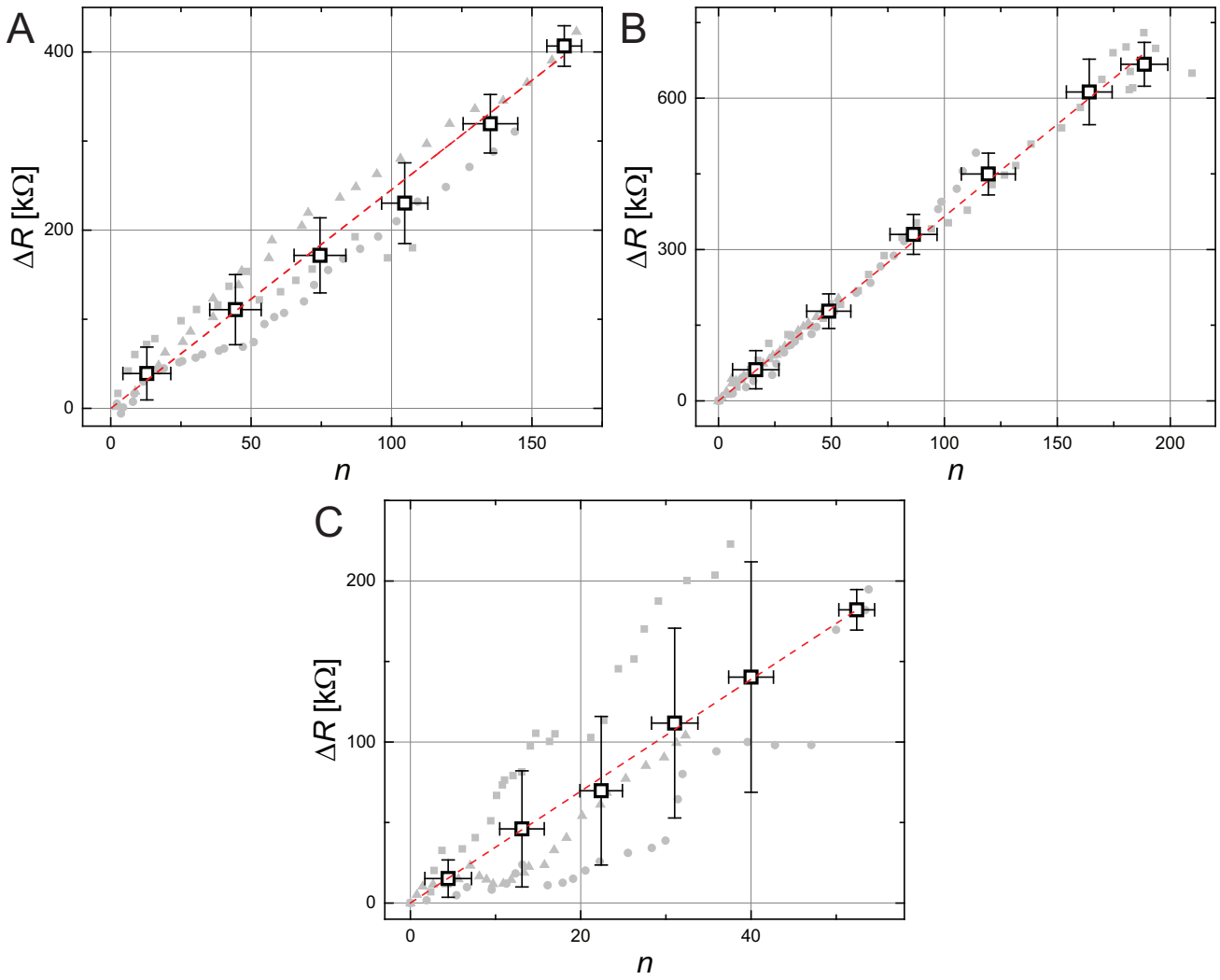

Fig. S3. Resistance change ΔR as a function of the number n of bacteria in the microchannels from three independent experiments. (*A*) *K. pneumoniae*. (*B*) *E. coli*. (*C*) *S. saprophyticus*. The red dashed line in each figure shows the linear fit.

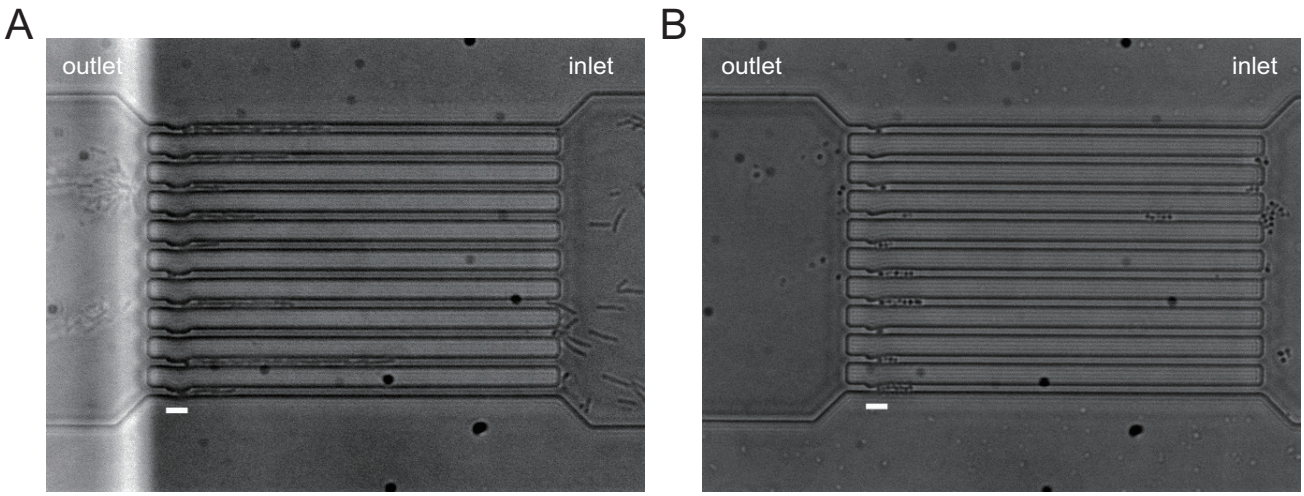

Fig. S4. Microscope snapshots showing bacteria accumulation outside the microchannels. (*A*) *E. coli* (ATCC 25922) growing in LB broth in nalidixic acid (20 mg/L). The bacteria that escaped through the nanoconstriction have proliferated in the outlet region. (*B*) *S. saprophyticus* (ATCC 15305) growing in LB broth in ampicillin (10 mg/L). Some cells have accumulated at the entry regions of the microchannels. The scale bars are 5 μm.

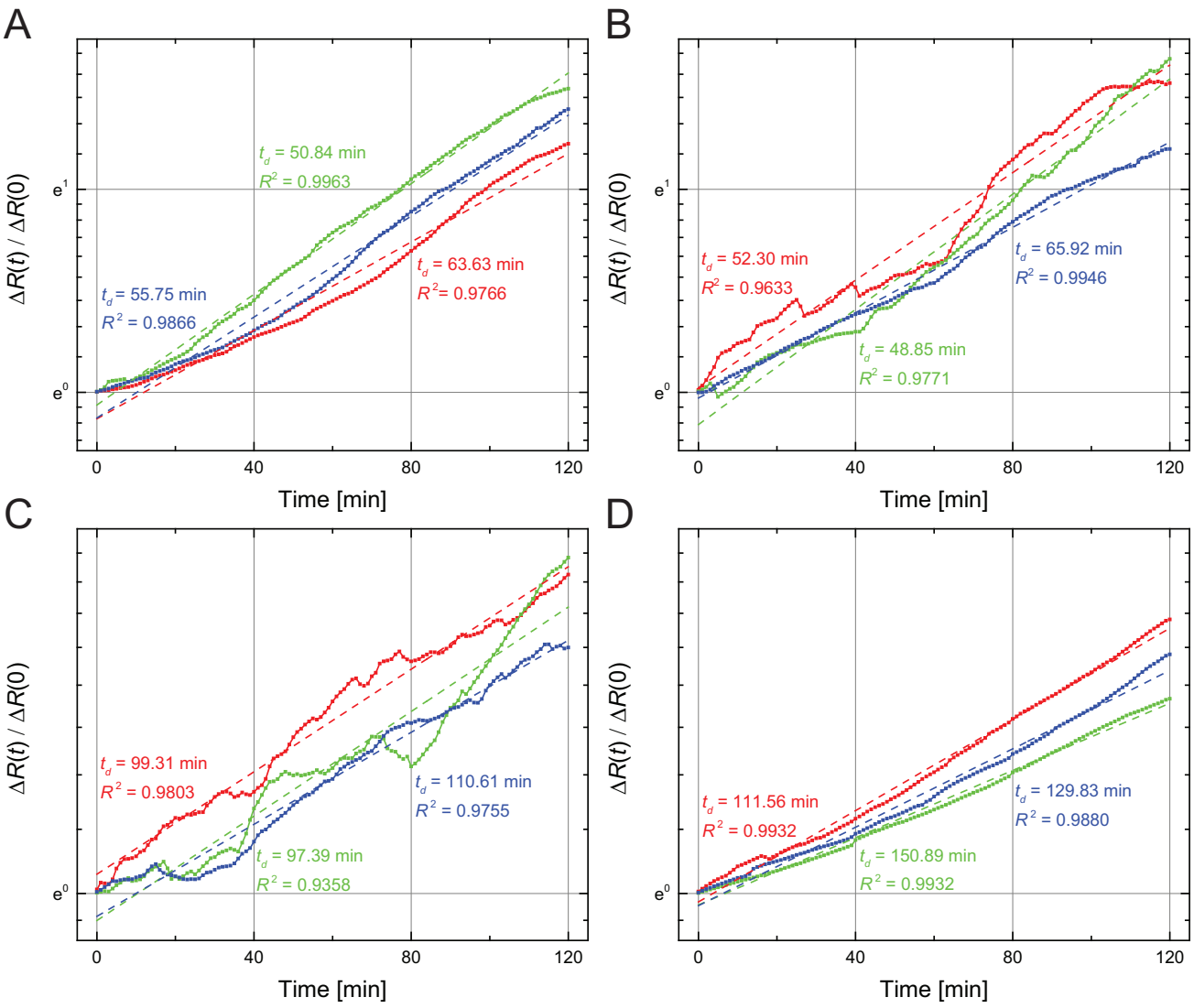

Fig. S5. Linear fits to the natural logarithm of $\frac{\Delta R(t)}{\Delta R(0)}$ in order to determine the bacterial doubling time in the microchannels. (*A*) *E. coli* (ATCC 25922) at $37\ ^{\circ}$C. (*B*) *K. pneumoniae* (ATCC 13883) at $37\ ^{\circ}$C. (*C*) *S. saprophyticus* (ATCC 15305) at $37\ ^{\circ}$C. (*D*) *E. coli* (ATCC 25922) at $23\ ^{\circ}$C. Solid lines show data from independent experiments; the dashed lines show the linear fits.

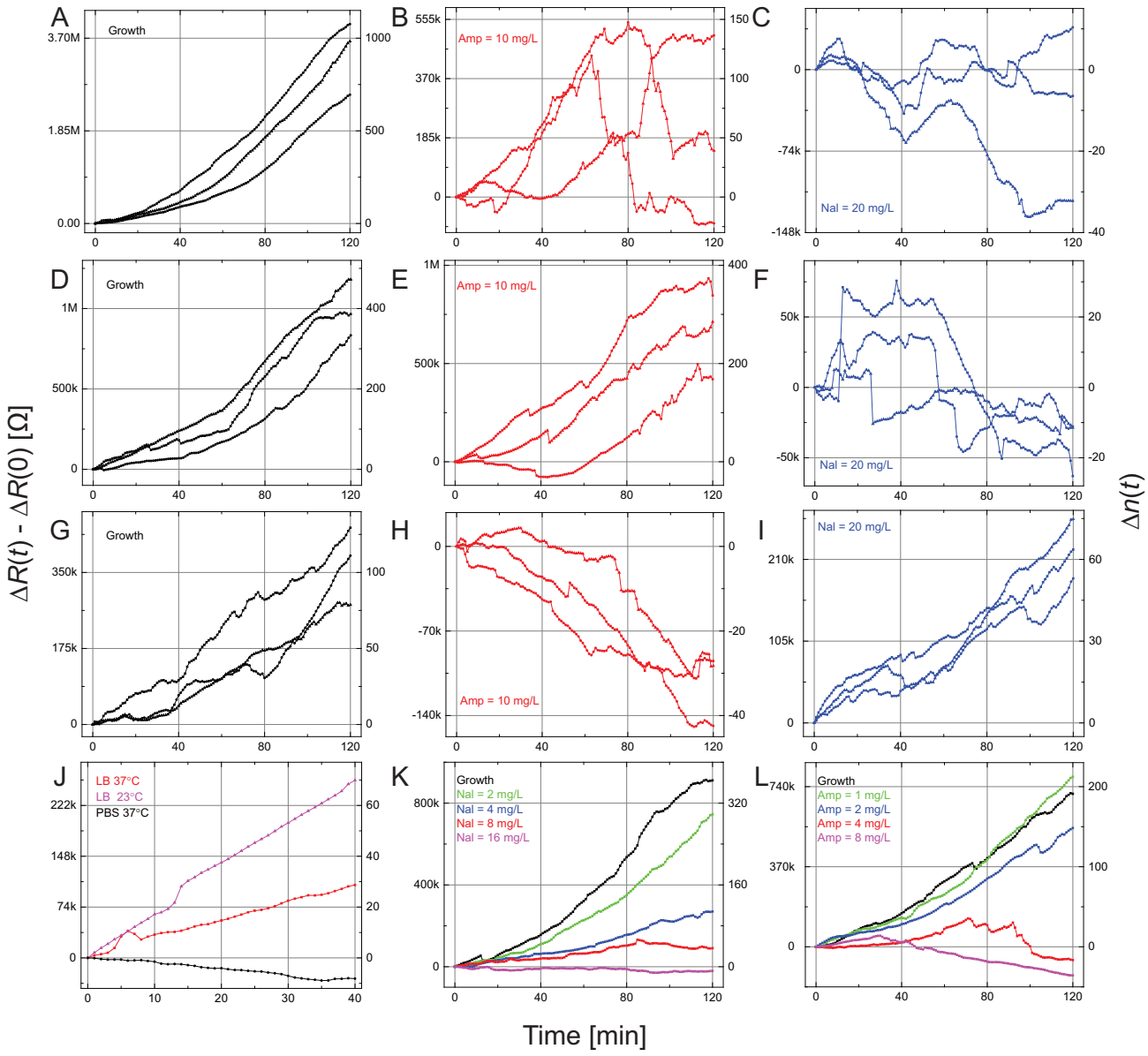

Fig. S6. Measured resistance change $\Delta R(t) - \Delta R(0)$ and change in the number of bacteria, $\Delta n(t)$, in the microchannels after sample loading as a function of time. Measurements on *E. coli* (ATCC 25922) (*A-C*), *K. pneumoniae* (ATCC 13883) (*D-F*), *S. saprophyticus* (ATCC 15305) (*G-I*). (*J*) Measurements on *E. coli* (ATCC 25922) in PBS at 37°C and LB broth at 23°C and 37°C. (*K*) Measurements on *K. pneumoniae* (ATCC 13883) growing in urine with nalidixic acid at different concentrations. (*L*) Measurement on *E. coli* (JW 1908-1) growing in urine with ampicillin at different concentrations. Each curve represents one independent experiment.

Table S1. Summary of MICs of ampicillin and nalidixic acid for *E. coli*, *K. pnuemoniae* and *S. saprophyticus* obtained by resazurin-based broth multidilution AST. Results obtained in urine are shown in parentheses.

Bacteria	Ampicillin (mg/L)	Nalidixic acid (mg/L)
E. coli (ATCC 25922)	8	4-8
K. pnuemoniae (ATCC 13883)	> 128	16 (8)
S. saprophyticus (ATCC 15305)	< 0.25	> 128
E. coli (JW 1908-1)	(4)	-

Table S2. Average growth rates $\bar{r}$ for all experiments without and with drift correction. Where available, both the average values and the results of individual experiments (in parentheses) are tabulated.

Bacteria	Antibiotic	Expectation	$\bar{r}$ (min^{-1})	Drift-corr. $\bar{r}$ (min^{-1})
E. coli	Growth (LB)	-	0.019 (0.021, 0.018, 0.019)	0.019 (0.021, 0.018, 0.019)
E. coli	Ampicillin, 10 mg/L	Susceptible	-0.0037 (-0.0005, -0.0099, -0.0006)	-0.0027 (0.0003, -0.0093, 0.0008)
E. coli	Nalidixic acid, 20 mg/L	Susceptible	-0.0017 (-0.0011, 0.0012, -0.0052)	-0.0008 (-0.0005, 0.0023, -0.0043)
K. pnuemoniae	Growth (LB)	-	0.021 (0.022, 0.026, 0.015)	0.021 (0.022, 0.026, 0.015)
K. pnuemoniae	Ampicillin, 10 mg/L	Resistant	0.0114 (0.0096, 0.0176, 0.0070)	0.0118 (0.0099, 0.0184, 0.0071)
K. pnuemoniae	Nalidixic acid, 20 mg/L	Susceptible	-0.0019 (-0.0044, 0.0013, -0.0027)	-0.0010 (-0.0034, 0.0019, -0.0014)
S. saprophyticus	Growth (LB)	-	0.010 (0.007, 0.015, 0.009)	0.010 (0.007, 0.015, 0.009)
S. saprophyticus	Ampicillin, 10 mg/L	Susceptible	-0.0096 (-0.0058, -0.0068, -0.0161)	-0.0071 (-0.0039, -0.0051, -0.0124)
S. saprophyticus	Nalidixic acid, 20 mg/L	Resistant	0.0059 (0.0052, 0.0055, 0.0069)	0.0064 (0.0057, 0.0062, 0.0072)
K. pnuemoniae	Growth (urine)	-	0.018	0.018
K. pnuemoniae	Nalidixic acid, 2 mg/L	Resistant	0.018	0.018
K. pnuemoniae	Nalidixic acid, 4 mg/L	Resistant	0.0059	0.0062
K. pnuemoniae	Nalidixic acid, 8 mg/L	Resistant	0.0006	0.0012
K. pnuemoniae	Nalidixic acid, 16 mg/L	Susceptible	-0.0008	-0.0002
E. coli	Growth (urine)	-	0.013	0.013
E. coli	Ampicillin, 1 mg/L	Resistant	0.017	0.017
E. coli	Ampicillin, 2 mg/L	Resistant	0.0125	0.0126
E. coli	Ampicillin, 4 mg/L	Susceptible	-0.0232	-0.0197
E. coli	Ampicillin, 8 mg/L	Susceptible	-0.0193	-0.0136

Table S3. Initial resistances $R(0)$ for each electrical measurement. Experiments in urine are shown in parentheses.

Bacteria	Growth ($\mathrm{M}\Omega$)	Ampicillin ($\mathrm{M}\Omega$)	Nalidixic acid ($\mathrm{M}\Omega$)
E. coli ATCC 25922	4.02, 4.10, 4.15	3.47, 3.95, 3.99	3.59, 3.24, 3.59
K. pnuemoniae ATCC 13883	3.22, 3.15, 3.46	3.65, 3.47, 3.91	3.41, 3.55, 3.28 (3.24, 3.21, 3.52, 3.45, 3.60)
S. saprophyticus ATCC 15305	3.28, 3.22, 3.24	3.29, 3.37, 3.19	3.28, 3.16, 3.43
E. coli JW 1908-1	-	(3.23, 3.27, 3.26, 3.18, 3.16)	-

Table S4. Rough number of bacteria trapped in the microchannel region in each experiment as determined from microscope images. Experiments in urine are shown in parentheses.

Bacteria	Growth	Ampicillin	Nalidixic acid
E. coli (ATCC 25922)	90, 95, 95	70, 95, 95	75, 50, 75
K. pnuemoniae (ATCC 13883)	60, 50, 85	85, 65, 95	60, 70, 50 (60, 60, 70, 65, 80)
S. saprophyticus (ATCC 15305)	60, 60, 50	45, 60, 45	40, 50, 65
E. coli (JW 1908-1)	-	(60, 55, 40, 30, 35)	-

Movie S1. ***E.coli*** **(ATCC 25922) growth with no drug in the microchannels in LB broth at** 37°**C. (Left) Time-lapse imaging showing that the cells are immobilized and growing in the microchannels. Scale bar, 5** μ**m. (Right) The normalized electrical resistance change** $\frac{\Delta R(t)}{\Delta R(0)}$ **of the microchannels as a function of time. Each second in the video corresponds to** ~ 3 **min in the experiment.**

Movie S2. ***E. coli*** **(ATCC 25922) growth in the presence of ampicillin (10 mg/L) in the microchannels in LB broth at** 37°**C. (Left) Time-lapse images show that the trapped cells are elongating and swelling, but do not divide, and finally burst in the microchannels. Scale bar, 5** μ**m. (Right) The normalized electrical resistance change** $\frac{\Delta R(t)}{\Delta R(0)}$ **and the resistance fluctuations of the microchannels as a function of time. Each second in the video corresponds to** ~ 3 **min in the experiment.**

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