How bacteria swim against the flow

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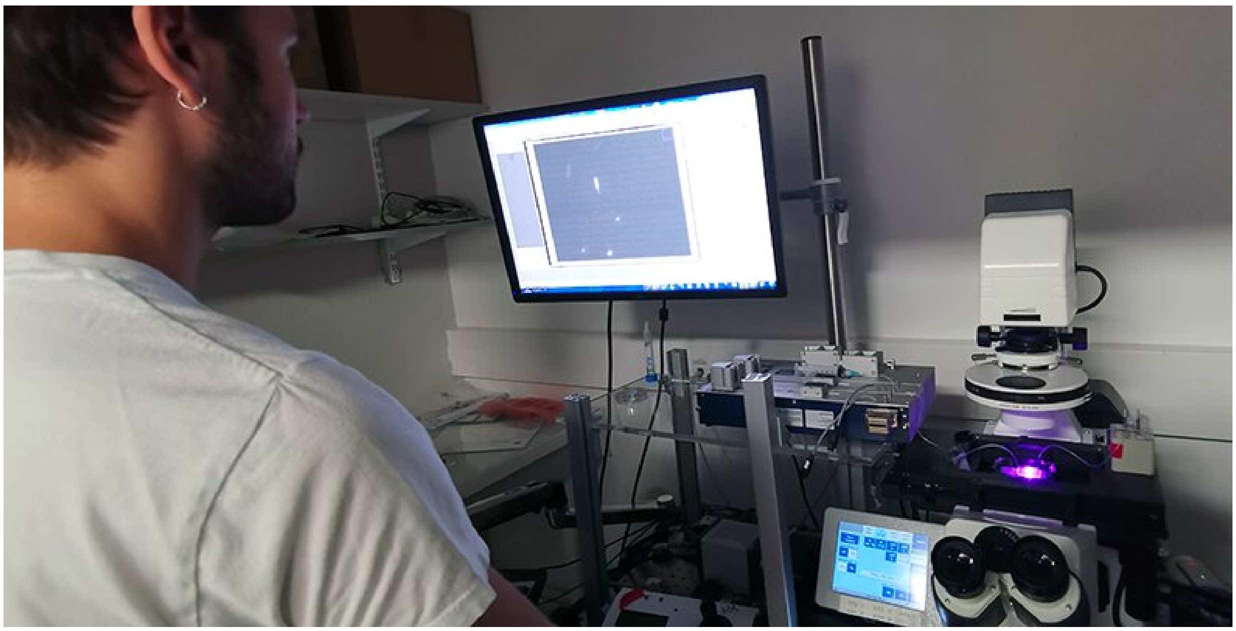


Set up at PMMH Lab. Credit: ESPCI Paris

It is well known that bacteria can swim against the current, which often causes serious problems—for example, when they spread in water pipes or in medical catheters. To prevent or at least slow down the spread of bacteria contaminating biological or medical ducts, scientists need to know how they swim against the flow. An international research team, including the group of Anke Lindner and Eric Clement at PMMH lab from ESPCI Paris (PSL University), was recently able to answer this question with the help of experiments and mathematical calculations.

The results describing all essential aspects of this amazing bacterial behavior have now been published in *Nature Communications*. These insights could contribute to the design of medical devices that hinder the upstream progress of bacteria.

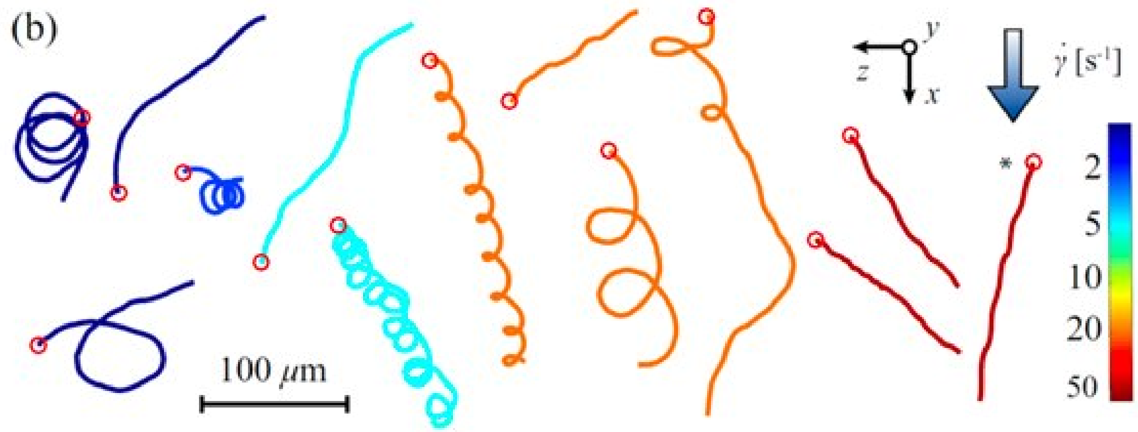
Between Physics and Biology

Many types of bacteria such as E. coli move around using small helicoidal flagella tails, but in a way quite different from the motion of a fish. Fish feel the direction of the current and can decide to swim in a specific direction, whereas bacteria are much simpler, and their behavior can be explained by very basic physical laws.

Bacteria often accumulate on surfaces submerged in liquids, as in a poorly cleaned shower cubicle, a sewage pipe or even a catheter. It turns out that bacteria migrate against the current on such surfaces. They are therefore not washed away with the wastewater, but rather move upstream. Together with colleagues from Stanford University, Oxford University and TU Wien, Anke Lindner and Eric Clement's group set out to find a physical explanation for this effect.

Theory and experiment

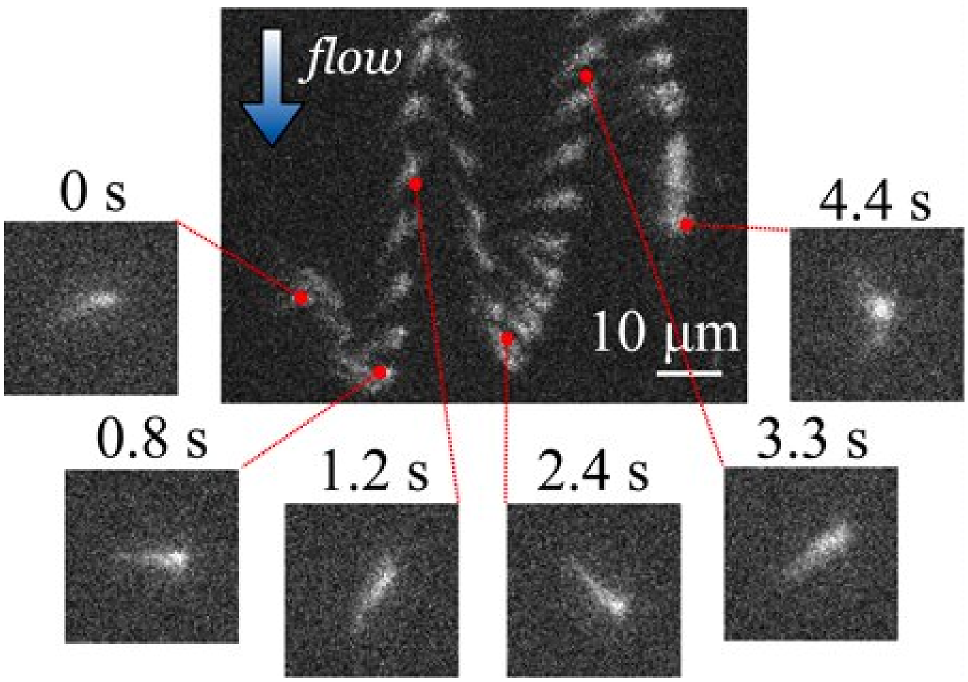
To track bacterial responses to flowing current, the PMMH group monitored E. coli in microfluidic channels a few hundreds of microns in width—about that of a strand of hair. They steadily ramped up the rate at which media flowed through the channels to observe the resulting bacterial dynamics.



Several types of E. coli bacteria experimental trajectories under flow near a surface. the flow increases from left to right. Credit: *Nature Communications*, 2019. 10.1038/s41467-019-11360-0

The researchers recently developed very powerful observation tools, and using an automatic 3-D tracking device, they were able to follow bacteria along their upstream swimming trajectories. Via fluorescent staining, they observed bacteria and their flagella, discovering an oscillatory motion of the bacteria. "It is fascinating how, by looking through a microscope, the dynamics of bacteria can be revealed with such precision," reports Anke Lindner.

These experimental observations revealed rich behavior as a function of the applied flow rate. In slow currents, the bacteria simply rotate in a circle. At a certain point, they begin to move against the direction of flow. In even stronger currents, they oscillate back and forth on the surface, or they separate into two different groups that move in different directions.



Oscillations of fluorescently stained E. coli bacteria under flow near a surface. Credit: *Nature Communications*, 2019. doi: 10.1038/s41467-019-11360-0

The teams from TU Wien and Stanford used mathematical methods to calculate how a bacterium can be aligned and rotated in a flowing liquid. They analyzed how the flow interacts with the movement of the flagella and which bacteria movement possibilities result from this. With a single mathematical formula, the whole range of bacterial movement patterns could be explained. "The agreement between experiments and simulations is found to be extremely good" points out Anke Lindner, "confirming the power of the developed mathematical formula." In addition, the results are very robust and do not depend on specific details, they can this be applied to different types of bacteria.

The team hopes that the newly gained understanding of bacterial motion will enable them to find methods that prevent bacteria from moving upstream. "In future, it might be possible to equip catheters with a specific geometric surface structure that prevents bacteria from migrating against the current and thus preventing serious infections to occur," hopes Anke Lindner.

More information: Oscillatory surface rheotaxis of swimming E. coli bacteria, *Nature Communications*, 2019.
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