Secrets of microbial motion: How bacteria swash, glide and shift gears to survive

2 new studies reveal surprising ways microbes move, with implications for human health and disease

By Richard Harth, ASU News
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New studies from Arizona State University reveal surprising ways bacteria can move without their flagella — the slender, whip-like propellers that usually drive them forward.

Movement lets bacteria form communities, spread to new places or escape from danger. Understanding how they do it can help us develop new tools to fight against infections.

In the first study, Navish Wadhwa and colleagues show that salmonella and E. coli can move across moist surfaces even when their flagella are disabled. As part of their metabolism, the bacteria ferment sugars and set up tiny outward currents on the moist surface. These currents carry the colony forward, like leaves drifting on a thin stream of water.

The researchers call this new form of movement “swashing.” It may help explain how harmful microbes successfully colonize medical devices, wounds or food-processing surfaces. Understanding how metabolism drives bacterial movement could help researchers develop new techniques to limit infections, for example by changing local pH or sugar availability.

“We were amazed by the ability of these bacteria to migrate across surfaces without functional flagella. In fact, our collaborators originally designed this experiment as a 'negative control,' meaning that we expected (once rendered) flagella-less, the cells to not move,” Wadhwa says. “But the bacteria migrated with abandon, as if nothing were amiss, setting us off on a multiyear quest to understand how they were doing it.

"It just goes to show that even when we think we’ve got something figured out, there are often surprises waiting just under the surface, or in this case, above it.”

Wadhwa is a researcher with the Biodesign Center for Mechanisms of Evolution and assistant professor with the Department of Physics at ASU.

The study appears in the Journal of Bacteriology. The paper has been selected by the journal as an Editor's Pick, highlighting the importance of the research.

Sugar-fueled swashing

When bacteria feed on sugars like glucose, maltose or xylose, they sometimes give off acidic by-products such as acetate and formate. These by-products draw water from the surface, creating currents that push the bacteria outward. Fermentable sugars are essential for this process — without them, the microbes can't move in this way. Sugar-rich environments in the body, such as mucus, may actually help harmful bacteria spread and cause infection.

When researchers added detergent-like molecules known as surfactants to the colonies, the bacteria stopped swashing. In contrast, surfactants did not affect swarming, a coordinated, flagella-powered form of movement that lets bacteria spread rapidly across moist surfaces. This suggests the two forms of movement use distinct physical mechanisms, and that surfactants that can be used to selectively suppress (or enhance) the movement of bacteria depending on whether they are swashing or swarming.

The fact that bacteria can colonize surfaces even when their normal swimming machinery is impaired has important implications for human health. Some microbes may spread by swashing across medical catheters, implants and hospital equipment. Blocking flagella alone may not be enough to stop them. Instead, we may need to interfere with the chemical processes they use to power this movement.

Both E. coli and salmonella can cause foodborne illness. Knowing they can spread on surfaces through passive fluid flows may help improve how food processing plants design cleaning protocols. And because swashing depends on fermentation and acidic by-products, strategies that alter surface pH or sugar availability could reduce bacterial colonization. The study showed that simple changes in acidity were enough to alter how the bacteria moved.

Something similar may also occur inside the body, where moist surfaces like gut mucus, wound fluids or the urinary tract create favorable conditions for bacteria. In these places, bacteria could use swashing to spread even when their flagella don't work well.

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Shifting strategies

In a second study, corresponding author Abhishek Shrivastava and his colleagues looked at a type of bacteria known as flavobacteria. Unlike E. coli, these bacteria don't swim; rather, they navigate environmental and host-associated surfaces using a machine called the type 9 secretion system, or T9SS, which propels a molecular conveyor belt.

Normally, the T9SS helps these bacteria glide across surfaces. It does this by moving an adhesive-coated belt around the cell body, pulling the bacterium forward like a microscopic snowmobile. The researchers discovered that a conveyor-belt protein called GldJ acts like a gear-shifter, controlling the direction of this rotary motor.

If a small part of GldJ is deleted, the motor flips its spin from counterclockwise to clockwise, changing how the bacteria move. The study describes this molecular gearset in detail and shows how it allows bacteria to fine-tune their direction of movement, giving them an evolutionary edge in navigating complex environments.

Beyond enabling bacterial movement, the T9SS also has major implications for human health — serving both harmful and beneficial roles depending on the microbial community. In the human oral microbiome, T9SS-containing bacteria are linked to gum disease, where their secreted proteins promote inflammation in the mouth and brain, contributing to disorders such as heart disease and Alzheimer's. Conversely, in the gut microbiome, T9SS-secreted proteins can protect antibodies from degradation, thereby strengthening immunity and improving the efficacy of oral vaccines.

Understanding how this gearbox works could help scientists design ways to block bacteria from forming slimy bacterial communities known as biofilms, causing infections and contaminating medical devices, but also harness its beneficial properties to promote health and develop targeted microbiome therapies.

“We are very excited to have discovered an extraordinary dual-role nanogear system that integrates a feedback mechanism, revealing a controllable biological snowmobile and showing how bacteria precisely tune motility and secretion in dynamic environments," Shrivastava says. “Building on this breakthrough, we now aim to determine high-resolution structures of this remarkable molecular conveyor to visualize, at atomic precision, how its moving parts interlock, transmit force and respond to mechanical feedback. Unraveling this intricate design will not only deepen our understanding of microbial evolution but also inspire the development of next-generation bioengineered nanomachines and therapeutic technologies.”

Shrivastava is a researcher with the Biodesign Center for Fundamental and Applied Microbiomics, the Biodesign Center for Mechanisms of Evolution, and assistant professor with ASU's School of Life Sciences. The research appears in the journal mBio.

At first glance, the two discoveries — fluid surfing and molecular gear-shifting, seem worlds apart. But they share a common theme: bacteria have evolved multiple, surprising ways to spread. The more strategies bacteria have, the harder they are to contain.

The new findings also underscore the need for fresh thinking in combating bacterial disease. Many traditional approaches have often focused on targeting flagella. But as these studies show, bacteria can get around that limitation.

The research suggests that controlling the bacterial environment, including factors like sugar levels, pH and surface chemistry, may be just as important as targeting bacterial genes. And disrupting key molecular machines like the T9SS gearbox could prevent bacteria not only from moving but also from secreting the proteins that make them dangerous.

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Main image

Bacteria can effectively travel even without their propeller-like flagella — by “swashing” across moist surfaces using chemical currents, or by gliding along a built-in molecular conveyor belt. Graphic by Jason Drees/ASU

Text image(s)

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