Bacterial attachment mimics the just-in-time industrial delivery model

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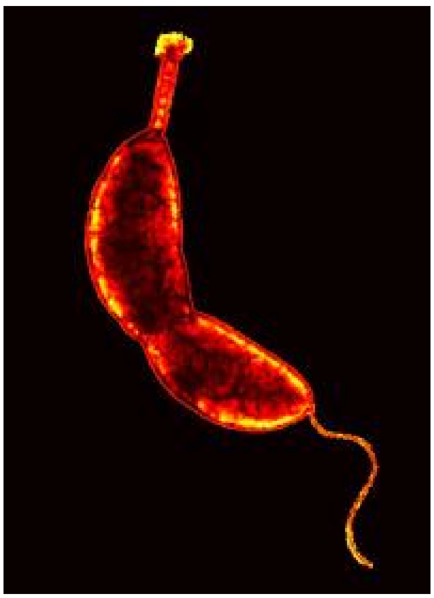

Caulobacter crescentus with the holdfast pili at top and the propelling flagellum at the opposite end. Credit: Indiana University

(PhysOrg.com) -- In the human world of manufacturing, many companies are now applying an on-demand, just-in-time strategy to conserve resources, reduce costs and promote production of goods precisely when and where they are most needed. A recent study from Indiana University Bloomington scientists reveals that bacteria have evolved a similar just-in-time strategy to constrain production of an extremely sticky cement to exactly the appropriate time and place, avoiding wasteful and problematic production of the material.

Indiana University biologists and two physicists at Brown University with IU connections have shown that certain bacteria wait until the last minute to synthesize the glue that allows them to attach permanently to surfaces. Binding efficiently to surfaces is extremely important to bacteria in the environment and for bacterial disease agents during the infection process.

The researchers found that bacteria -- including the freshwater bacterium Caulobacter crescentus and the agricultural pathogen Agrobacterium tumefaciens -- first connect to a surface with the cellular equivalents of propellers and cables and that this initial, reversible contact stimulates the synthesis of a sticky glue. This holdfast adhesin, which is composed of polysaccharide sugar molecules, is then released only at the site of surface contact to irreversibly attach the bacteria to host surfaces.

The study, "Surface contact stimulates the just-in-time deployment of bacterial adhesins," was published earlier this month in Molecular Microbiology . It describes how single bacterial cells use their flagella (the propellers) and pili (the cables) to facilitate the timely release of adhesive polysaccharides upon initial contact with other surfaces.

Microbiologists are generally interested in bacterial adhesion and formation of complex microbial communities called biofilms that can clog pipes, slow down ships and establish antibiotic-resistant infections. Efficient surface attachment strategies are advantageous to bacteria as they can increase nutrient access and resistance to environmental stress, including host defenses.

"For bacteria, surface attachment by single cells is the first step to important processes such as biofilm formation and host infection," said IU microbiologist Pamela Brown, one of the project's lead authors. "What we found is that the interaction of bacterial cells with a surface using their flagellum and pili stimulates the on-the-spot production of polysaccharide adhesins, propelling the transition from transient to permanent attachment."

The new findings also suggest that pathogenic bacteria may carefully time adhesin release to protect themselves from premature exposure to a host's immune system during infection.

The team used cutting-edge, high-resolution video microscopy to observe the single-cell attachment process in real time in the presence of a fluorescent stain that decorates the adhesive polysaccharide. They found that when Caulobacter cells are propelled to a surface by their rotating propeller-like single flagellum, the flagellar motor stopped immediately upon contact with the surface. Inhibition of flagellar rotation was quickly followed by the production of the holdfast polysaccharide adhesin, specifically from the cell pole containing the now inactive flagellum, and in contact with the surface.

"We knew that cable-like pili are present at the same pole of the cell as the flagellum, and we hypothesized that they played a key role in the process by interacting with the surface, thereby preventing the free rotation of the flagellum," said IU microbiologist Yves Brun, the project's principal investigator. Indeed, when the team made a mutation that abolished the pili, the cells became tethered to the surface by their flagellum, but its rotation continued and the cell eventually detached.

The team hypothesizes that just-in-time adhesin production may be a general phenomenon since they obtained similar results with two other bacterial species, Agrobacterium tumefaciens and Asticcacaulis biprosthecum.

"What is striking is that we found that this mechanism does more than stimulate binding to inert surfaces. It also operates when the plant pathogen Agrobacterium tumefaciens binds to host tissue," said IU microbiologist Clay Fuqua, who recently discovered the holdfast-type adhesin used by this bacterium to attach to plant tissue. "We think that the ability to rapidly deploy this permanent adhesin may be advantageous for swimming cells attempting to colonize a favorable environment."

Since pathogens such as Escherichia coli and Pseudomonas aeruginosa also attach by their pole prior to their transition from reversible to irreversible attachment, the authors hypothesize that this mechanism could also be at play during the infection process.

"Once we know more about the details of this mechanism, we may be able to design drugs that prevent this adhesin stimulation, therefore reducing the efficiency of infections," Brown said.

Research from Brun's laboratory and that of Brown University physicist Jay Tang on bacterial glues published in 2006 (see: www.physorg.com/news63981444.html) received international attention after they showed that the holdfast "glue" released by the tiny Caulobacter cells was the strongest in nature with a pulling force of 1 micronewton, equivalent to holding three or four cars with glue spread on the surface of a quarter.

"For such a strong adhesive, it may be important to avoid producing it too early because it might lose its efficiency, or it might get the cells irreversibly bound to the wrong surface. The analogy to the human world is amazing: You don't apply glue hours before you want to use it because it cures and hardens," Brun said.

Timing is everything, and with just-in-time adhesive production, cells have a better chance for efficient surface interaction and colonization because the two main factors in reducing adhesion -- curing and coating of glue with small particles -- are inhibitory mechanisms that require time to decrease adhesiveness. The on-the-spot production of adhesins circumvents this problem.

More information: "Surface contact stimulates the just-in-time deployment of bacterial adhesins," by Guanglai Li; et al;*Molecular Microbiology*, published Nov. 22, 2011; DOI: 10.1111/j.1365-2958.2011.07909.x.

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