Electric Field Detaches Tethered *C. crescentus* and Drives Bacterial Rolling Motion

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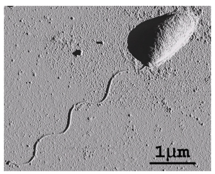
Abstract

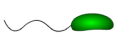
Bacterial tethering to solid surfaces facilitates many crucial functions in their natural habitats. The goal of this research is to understand the mechanisms of cell body tethering to solid surfaces. In particular, this project studies the tethering and detaching mechanisms of *C. crescentus.* We apply an electric field as a means to detach the cells from the surface. By manipulating the field strength and observing its influence on the tethered cell, we found that the tethering strengths of the younger, swarmer cells is stronger than that of the older, especially, pre-divisional cells. We found that a 1000V/m electric field was sufficient to detach some tethered pre-divisional cells, causing them to roll over solid surface; the same field strength was insufficient to detach tethered swarmer cells.

Introduction

Caulobacter crescentus is a gram-negative, waterborne bacterium. It has distinct forms during its life cycle, as swarmer or stalked cells. A new swarmer cell is produced by dividing from a mature stalked cell every 2 hours under favorable growth conditions. At the swarmer or pre-divisional phase of its life cycle, each cell has a single rotating flagellum, enabling it to swim. This bacterium serves as a model organism for studying development. In this study, we focus on its adhesion to solid surfaces by imaging the cells tethered to a plastic surface and their subsequent motions driven by their flagella and an applied electric field.

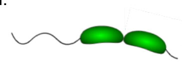


An AFM image of a *C. Crescentus* swarmer cell (Li, et al, Phys. Rev. E, 84:041932, 2011)



Swarmer cell

An early stage in *C. crescentus'* life cycle. It has a flagellum. Swarmer cell eventually loses its flagellum, grows a stalk and become a stalked cell.

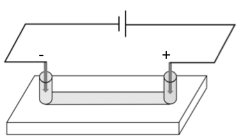


Pre-divisional cell

A stage before a new swarmer cell is divided from a mature stalked cell. It is motile, but less than a swarmer cell.

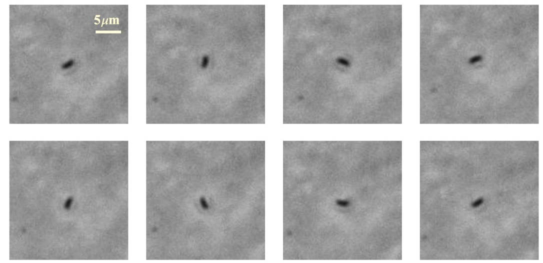
Method

This study uses the double mutant strain SB3860 (cheR138::Tn5 in YB375), which lacks pili and only swims in the forward direction with the flagellum pushing the cell body. SB3860 was cultured in peptone-yeast extract (PYE) for 20 hours. Then the bacterial solution was diluted 1:10 into 50mM $MgSO_4$ solvent. The mixture was instilled into a fluid channel (1mm x 5mm x 50mm) of a plastic capillary using a syringe pump. We observed the bacteria under a microscope using a 40x objective lens. An electric field was applied up to 1000V/m to detach the tethered bacteria.

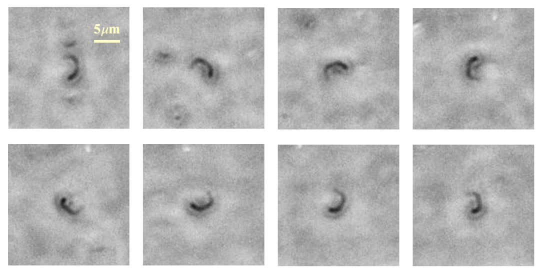


Results

Tethered Motion Differs between Swarmer Cells and Pre-divisional Cells

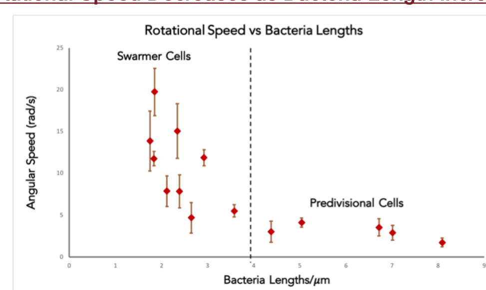


The frames display the motion of a tethered swarmer cell. The time interval between consecutive frames is 0.1s. The cell rotates counterclockwise around a fixed point, completing two turns during the illustrated sequence.



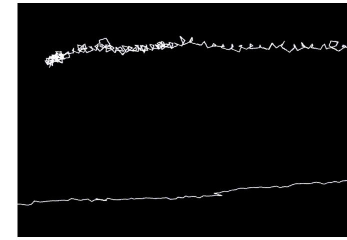
The pre-divisional cell is larger and completed only one turn during the same time interval.

Rotational Speed Decreases as Bacteria Length Increases

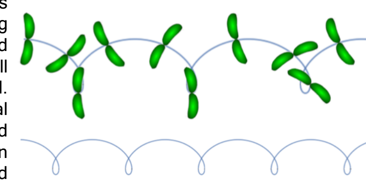


The figure shows an inverse relationship between the average angular speed of a tethered cell and its length. In general, swarmer cells (shorter than 4μm) rotate faster than pre-divisional cells (longer than 4μm).

Electric Field Causes Rolling Motion of Pre-divisional Cells



We found that the applied 1000V/m electric field to be insufficient to detach swarmer cells but sufficient to detach some tethered pre-divisional cells. This finding indicates that the tethering strength or mechanism may be different for swarmer cells and pre-divisional cells.



The top right figure compares the trajectories of a moving tethered pre-divisional cell and an untethered, nonmotile cell under the same electric field. The detached pre-divisional cell displays a trochoid trajectory. It is a combination of rotational motion and translational motion. The center of rotation of the pre-divisional cell moves in a straight line as the nonmotile cell while its cell body keeps the circular motion.

Also, for the pre-divisional cells, the average speed of the translational motion is the same as that of the nonmotile cells, half of that of the untethered swimming cells. These results suggest that the flagellum only contributes to the rotational motion while the translational motion is due to the electric field.

Summary of Key Findings

- Tethered swarmer cells rotate faster than tethered pre-divisional cells.
- The applied electric field was not strong enough to detach tethered swarmer cells but could detach the tethered pre-divisional cells. Therefore, the tethering mechanism of swarmer cells and pre-divisional cells may be different.
- The applied electric field drives tethered pre-divisional cells along the field while they keep the rotational motion, resulting in a trochoid trajectory (a combination of a translational motion and rotational motion).
- The translational speed of the rolling pre-divisional cell is the same as non-swimming cells; they move slower than freely swimming cells.

Acknowgements

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