Investigating the motility of swimming Euglena

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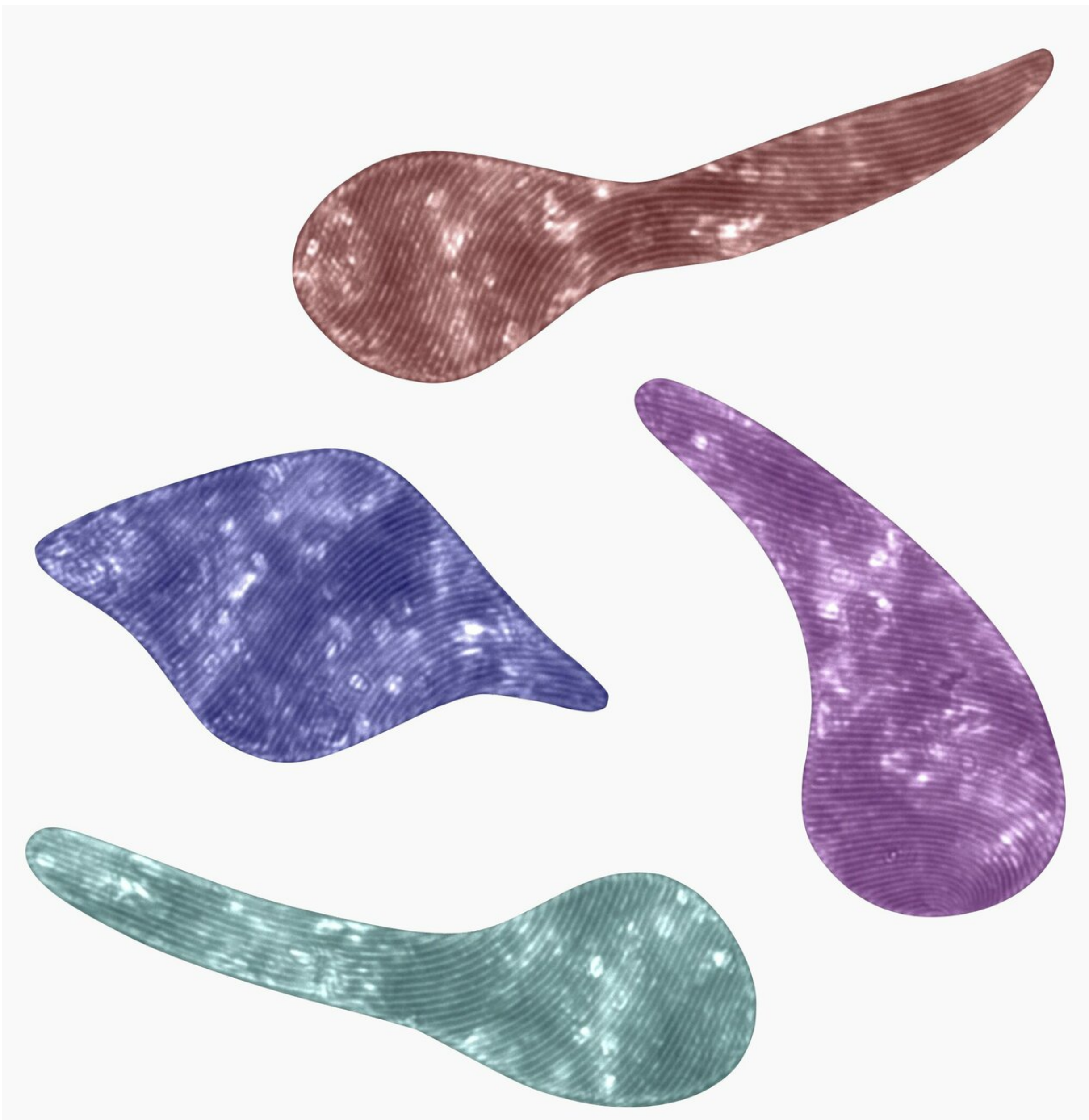

Credit: Noselli et al.

Some species of Euglenids, a diversified family of aquatic unicellular organisms, can perform large-amplitude, elegantly coordinated body deformations. Although this behavior has been known for centuries, its function is still highly debated.

Researchers at SISSA, the National Institute of of Oceanography and Applied Geophysics (OGS), Scuola Superiore Sant'Anna and Universitat Politècnica de Catalunya have recently carried out a study investigating the motility of Euglena Gracilis, a Euglenid, particularly in its response to confinement. In their study, published in *Nature Physics*, they examined the responses of swimming Euglena gracilis in environments of controlled crowding and geometry.

"The large-amplitude coordinated movements of Euglena cells, called metaboly, have been described for centuries, and still today fascinate microbiologists, biophysicists and amateur microscopists," Marino Arroyo, one of the researchers who carried out the study, told Phys.org. "To our knowledge, no other unicellular organisms can move with such elegance and coordination. Yet, how and why they do it is a mystery. Curiosity was what drove us to study the motility of Euglena."

The large-amplitude and coordinated body deformations observed in Euglena are typically referred to as 'euglenoid movement,' or 'metaboly.' Metaboly varies greatly between species and sometimes even within a species, ranging from a rounding and gentle bend or twist to periodic and highly concerted peristaltic waves that travel along the cell body.

"Amongst biophysicists, metaboly was thought to be a way to swim in a fluid, where these cells live," Arroyo said. "However, protistologists are not convinced by this function for metaboly, since Euglena can swim very fast beating their flagellum, as do many other cell types. Instead, the predominant view is that metaboly is a functionless vestige 'inherited' from ancestors that used cell body deformations to engulf large prey. Watching cells executing such a beautiful and coordinated dance, we did not believe that it served no purpose. Our study started as an effort to substantiate such a non-scientific gut feeling."

Dilute cultures of Euglena cells generally swim using their flagellum and without changing their body shape. Arroyo and his colleagues, however, observed that as time passed and the fluid under the microscope evaporated, their culture became more crowded and cells started to develop metaboly.

"Inspired by these observations and amateur YouTube videos, we hypothesized that the cell deformations could be triggered by contact with other cells or boundaries in a crowded environment, and that under these conditions, metaboly could be useful to crawl, rather than swim," Antonio De Simone, another researchers involved in the study, told Phys.org. "Confirming this hypothesis was remarkably easy. As soon as we slightly pressed cells between two glass surfaces, or drove them into thin capillaries, they started to systematically perform metaboly, which resulted in the fastest crawling by any cell type, as far as we know," added Giovanni Noselli, the first author of the study.

Once they finished testing this hypothesis, the researchers started comparing the crawling behaviour they observed in Euglena with that of animal cells, for which a greater number of studies are currently available. Past studies observed that animal cells crawling in a thin tube tend to push against its walls in order to move forward and overcome the resistance of the fluid in the tube.

"We found that, thanks to their peristaltic deformations, Euglena can push either on the walls or on the fluid to move forward, making of metaboly a remarkably robust mode of confined locomotion," De Simone said. "They can actually move displacing very little fluid in a 'stealthy' propulsion mode, and they cannot be stopped even if the hydraulic resistance in the capillary is increased substantially."

In their experiments, Arroyo, De Simone, Noselli and their colleague Alfred Beran noticed that Euglena cells were able to adapt their gait to varying degrees of confinement. To perform this behavior, the cells could be using a sensory system to detect their surrounding environment and some form of internal information processing to adapt their activity according to the degree of confinement.

The researchers found this explanation perplexing, however, particularly seeing as Euglena are single cells with no nervous system. To better understand how a single Euglena cell can control such an adaptable and robust mode of locomotion, Arroyo and his colleagues computationally modeled the motile apparatus of Euglena cells, which is essentially a striated cell envelope.

"We wondered if their active envelope, called a pellicle, responsible for the cell deformations, would mechanically self-adapt to varying mechanical conditions," Arroyo said. "To examine this, we developed a computational model showing that the compliance of the materials and molecular motors that make up the active envelope of Euglena could explain this adaptability, which in robotics is called mechanical or embodied intelligence."

Arroyo and his colleagues gathered fascinating observations about the body deformations of some Euglenids, suggesting that this behavior could, in some cases, be triggered by confinement. In addition to demonstrating one function of metaboly, their study established a new category of cellular crawlers, which are particularly fast, robust and adaptable.

"If crawling by metaboly is so advantageous, one may wonder why it is not conserved amongst other species," Arroyo said. "The answer is that it requires an intricate machinery, the pellicle, which is a striated envelope made out of elastic strips connected by molecular motors. This selectively deformable surface lies somewhere between the rigid wall of plant cells and the fluid envelope of animal cells. Beyond biology, we think that the underlying physical/geometric principles that enable shape changes of this envelope can be applied to artificial engineered systems, e.g. in soft robotics."

The computational model developed by Arroyo and his colleagues could finally shed light on the function of widely documented euglenoid movements. Their findings suggest that the gait adaptability of these organisms does not require specific mechanosensitive feedback, but rather could be explained by the mechanical self-regulation of an elastic and extended motor system.

In their recent study, the researchers successfully identified one function of and the operating principles behind the adaptable body deformation of Euglena cells. They are now planning to further investigate the cellular mechanisms by which metaboly is triggered and by which cellular deformations propagate.

"We plan to examine metaboly across different species of Euglena," DeSimone said. "Preliminary observations reveal various flavors of metaboly. We are also working on building artificial materials and devices inspired in the active and deformable envelope of Euglena cells".

More information: Giovanni Noselli et al. Swimming Euglena respond to confinement with a behavioural change enabling effective

crawling, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0425-8
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