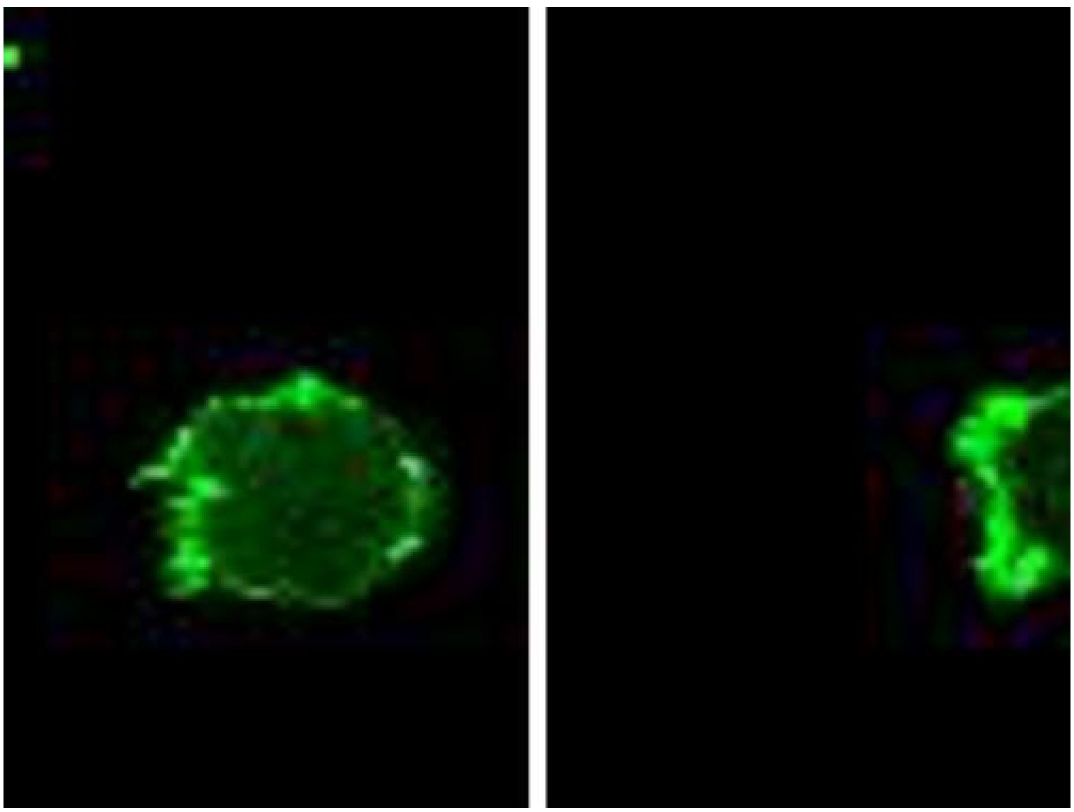
Even miniscule changes in environment can cause cytoskeleton of the amoeba Dictyostelium discoideum to oscillate

March 21 2013



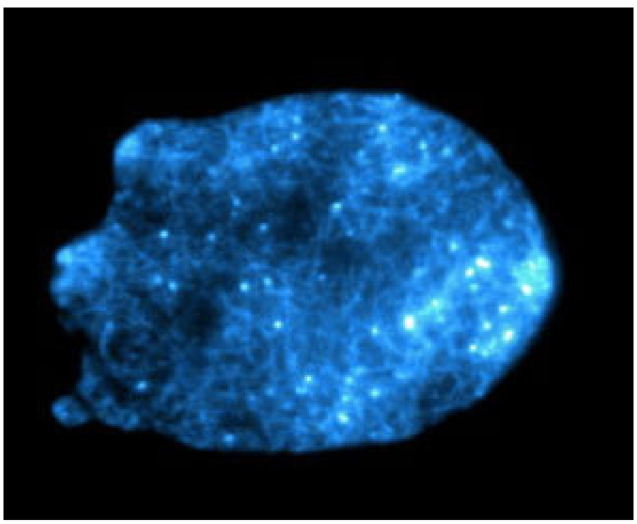
Movement of the cytoskeleton of the amoeba Dictyostelium discoideum is triggered by external chemical stimuli: the actin network is disassembled towards the interior of the cell and rebuilt towards the cell membrane at 20 second intervals. In the image on the left, there is still a lot of actin (green) in the cell interior. A few seconds later (right), the actin structure has shifted towards the cortical region close the cell membrane. Credit: MPIDS

(Phys.org) —The amoeba Dictyostelium discoideum is the "favourite animal" for many biologists and some physicists: the unicellular organism, which usually lives in the soil, serves as a model for a very wide range of cells, which are able to change their shape or move as soon as they sense changes in the chemical concentrations of their surroundings. Examples of such cells include cancer cells, embryonic stem cells at a very early stage in their development, and cells involved in wound healing. Scientists are now fascinated by a formerly unknown characteristic of this amoeba: it oscillates internally at a 20-second interval. Within this period, the cytoskeleton, which gives the cell its internal stability, can reorganise itself.

As part of the Collaborative Research Centre "Collective Behaviour of Soft and Biological Matter", physicists from the Max Planck Institute for Dynamics and Self-Organization (MPIDS) in Göttingen demonstrated that this enables the amoebae to react to minimal stimuli from their environment. The benefits obtained through this rhythmic internal renovation remain unclear. It is assumed that it helps the cell to move.

The amoeba Dictyostelium discoideum – often lovingly referred to as "Dicty"– is a sensitive creature: it can perceive even the tiniest variations in the chemical composition of its surroundings. This skill pays off in emergency situations. As soon as the amoeba's supply of nutrients becomes sparse, it transmits chemical calls for help to its neighbours. These consist of a tiny amount of the signalling substance cyclic adenosine monophosphate (cAMP). The Dictys in the vicinity register the signal and also transmit their own call for help. Circular and spiral-shaped "emergency-call" waves arise in a self-organized manner. The cells follow the calls, crawl to the centre of the wave and aggregate there. They then form a fruiting body with spores, which are conserved until the environment offers sufficient amounts of nutrition again. In their new experiments and calculations, the researchers in Göttingen have examined what happens in the interior of the individual cells when they receive the emergency call and turn on their internal "engine".

"Dicty is not the only cell that reacts to an external chemical stimulus," says Professor Eberhard Bodenschatz, Director at the MPIDS, explaining the motivation behind the new study. For example, embryonic cells are all identical at early stages of their development. But multicellular organisms, like human beings, consist of many different cell types. Only differences in the concentrations of certain signalling substances cause the cells to develop into different kinds, like brain cells, muscle cells, or bone cells. Here, the correct localization of the different cell types is of particular importance. It follows the same mechanism by which certain chemical substances stimulate cells to heal a wound.



A closer look at the amoeba Dictyostelium discoideum with fluorescence microscope shows the actin cytoskeleton: a network of fibres and tubes that extends close to the cell membrane. Credit: MPIDS

The structural protein actin plays a crucial role in this process. It can polymerize into a network of thin fibres that is localized at the interior side of the cell membrane, like a skeleton that maintains the shape and mechanical stability of the cell. Scientists refer to this structure as the actin cytoskeleton. External chemical stimuli cause this network to move: towards the interior of the cell, the actin network is disassembled while, at the same time, it is newly rebuilt towards the cell membrane.

"In our experiments, we deliberately exposed individual cells to a spatially and temporally well-defined change in the cAMP concentration," explains Christian Westendorf from the MPIDS, who performed the experiments. This was possible with the help of a substance called DMNB-cAMP. "A short laser pulse can split this component so that the signalling substance cAMP is released," explains Westendorf. To enable the scientists to trace the subsequent reaction of the cell under the microscope, its actin network was tagged with a fluorescent marker.

Unexpectedly, the images revealed that not all of the amoebae react in the same way. Whereas the cytoskeleton of some cells only moved outwards once and then returned to its initial state, in others cells several oscillations were observed. "In a small percentage of the cells, the actin structure actually oscillates with no external stimulus at all," says Westendorf.

To investigate these oscillations, the researchers performed further experiments and exposed the cells to periodic stimuli of cAMP. They found that a stimulation period of 20 seconds triggered the strongest reaction. "This proves that the 20-second rhythm is an intrinsic property of the Dicty cells," says Professor Carsten Beta, who works at the MPIDS and at the University of Potsdam. The behaviour of the cells can be compared to a pendulum, which oscillates at its own, unique frequency. The amplitude of the oscillation is largest when the pendulum is periodically driven at a pace similar to its intrinsic frequency.

But the results of this study reveal even more: "The amoebae clearly live on the edge of an instability," explains Bodenschatz. Even the smallest, barely measurable change in the external conditions can cause the cytoskeleton to oscillate – or to remain quiescent. A theoretical model, proposed by the researchers to describe the response dynamics of the cytoskeleton, supports this conclusion. A similar behaviour has been found, for example, for the hair cells in the inner ear. "Each of the cells is a very sensitive amplifier for external stimuli: tiny differences in the external conditions cause significant changes in behaviour," says Bodenschatz. As a result, the cells can react with particular sensitivity to such differences.

However, it is still unclear why the internal rhythm of the amoebae is found at periods of around 20 seconds. In their natural environment, the unicellular organisms are not exposed to such rapid signals. The calls for help emitted by their fellow cells arise at intervals of a few minutes. "However, when moving, the cells form membrane protrusions at intervals of ten to 20 seconds," says Bodenschatz. "It is possible that the cell needs this internal clock for its movement."

More information: Westendorf, C. et al. A closer look at the amoeba Dictyostelium discoideum with fluorescence microscope shows the actin cytoskeleton: a network of fibres and tubes that extends close to the cell membrane. *Proceedings of the National Academy of Sciences* (PNAS), Online Advance Publication, 19 February 2013. doi: 10.1073/pnas.1216629110

Provided by Max Planck Society