Tracing how cells learned to live without oxygen

Unusual microbes reveal how mitochondria can shrink, change or disappear as organisms adapt to low-oxygen environments

By Richard Harth, ASU News
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Mitochondria are among the most important structures inside living cells. These tiny compartments help generate the energy that powers not only our bodies, but also the cells of all eukaryotes (i.e., animals, plants, fungi and countless single-celled organisms like amoebae).

The origin of mitochondria was one of the most dramatic events in the history of life. More than a billion years ago, a bacterium took up residence inside another cell, eventually becoming part of the cell itself — the mitochondrion.

This event gave rise to a partnership that persists in nearly every eukaryotic cell today. Because mitochondria evolved from a bacterium, they contain their own genome (DNA), and this genome is necessary for any organism that uses oxygen to survive. However, some eukaryotes that can live without oxygen have radically altered or even lost their mitochondrial genome, or even the entire mitochondria itself. Our understanding of how this happens remains unclear, mostly due to a lack of sampling.

In a new study, researchers at Arizona State University and their collaborators used techniques to sequence tiny amounts of DNA from single isolated cells. By analyzing the genomes of these unusual single-celled eukaryotes from a mudflat in Maine, they identified a previously unknown lineage estimated to be about a billion years old. Their analysis revealed that some of these organisms have among the most complex mitochondrial genomes ever discovered, even though they live in low-oxygen environments.

Interestingly, these organisms are closely related to an anaerobic (oxygen-independent) group known as Breviatea, which lacks mitochondrial genomes and has highly reduced mitochondrial functions. Despite this close relationship, the newly discovered microbes possess mitochondrial genomes of remarkable complexity.

By comparing the two closely related groups, which have very different kinds of mitochondria, the researchers were able to trace how these cellular structures can become reduced and altered over evolutionary time.

“While the likelihood of discovering a new major lineage of animal is near zero, much of microbial diversity remains unknown and therefore major discoveries in diversity are still possible in our field,” says University Professor Jeremy Wideman, corresponding author of the new study. “In this case, we have identified a major lineage representing a missing link in evolution. By looking at their genomes, we can begin to understand how a particular lineage adapted to a low-oxygen environment.”

Wideman is a researcher with the Biodesign Center for Mechanisms of Evolution and ASU’s School of Life Sciences. The study was led by ASU postdoctoral research scholar Anna Cho, with collaborators from the Bigelow Laboratory for Ocean Sciences, the U.S. Department of Energy Joint Genome Institute at Lawrence Berkeley National Laboratory, and the University of California, Merced.

The research appears in the new issue of the journal Current Biology.

How to live without mitochondria

In environments where oxygen is scarce, such as the guts of animals or beneath sediments, some microbes have evolved unusual versions of mitochondria that no longer function as typical energy producers. Because mitochondria normally generate energy using oxygen, they become less useful in environments where oxygen is limited. These simplified structures carry out only a small subset of mitochondria’s usual tasks. In even rarer cases, researchers have discovered organisms that appear to have eliminated mitochondria entirely.

The new study adds to this growing picture. By examining the genomes of several related microbes, the researchers looked for genes that would normally be associated with mitochondria or their reduced forms. They identified interesting cells that have seemingly normal mitochondria that are closely related to a group of organisms with highly reduced mitochondria. This mix of cellular designs provides scientists with a valuable opportunity to study how mitochondria can change over time — and under what circumstances they might disappear.

The findings highlight an important lesson about evolution: Even features that seem universal can sometimes be lost if organisms find alternative ways to perform the same tasks. Instead of relying on mitochondria, these microbes appear to have reorganized their metabolism so that key chemical reactions happen elsewhere in the cell. In effect, they have rewired their internal systems to cope with life in environments where the usual energy-producing machinery would not function.

How evolution rewires cells

Studying these unusual organisms helps scientists understand just how adaptable cells can be. It also sheds light on early evolutionary events that shaped complex life. By examining how mitochondria can be reduced, transformed or lost, researchers gain clues about the original partnership between ancient cells and the bacteria that eventually became mitochondria.

While the microbes uncovered in the new study are tiny and obscure, their biology carries important implications. Although mitochondria are nearly universal among modern cells, these rare exceptions reveal how evolution can rework cellular machinery in unexpected ways.

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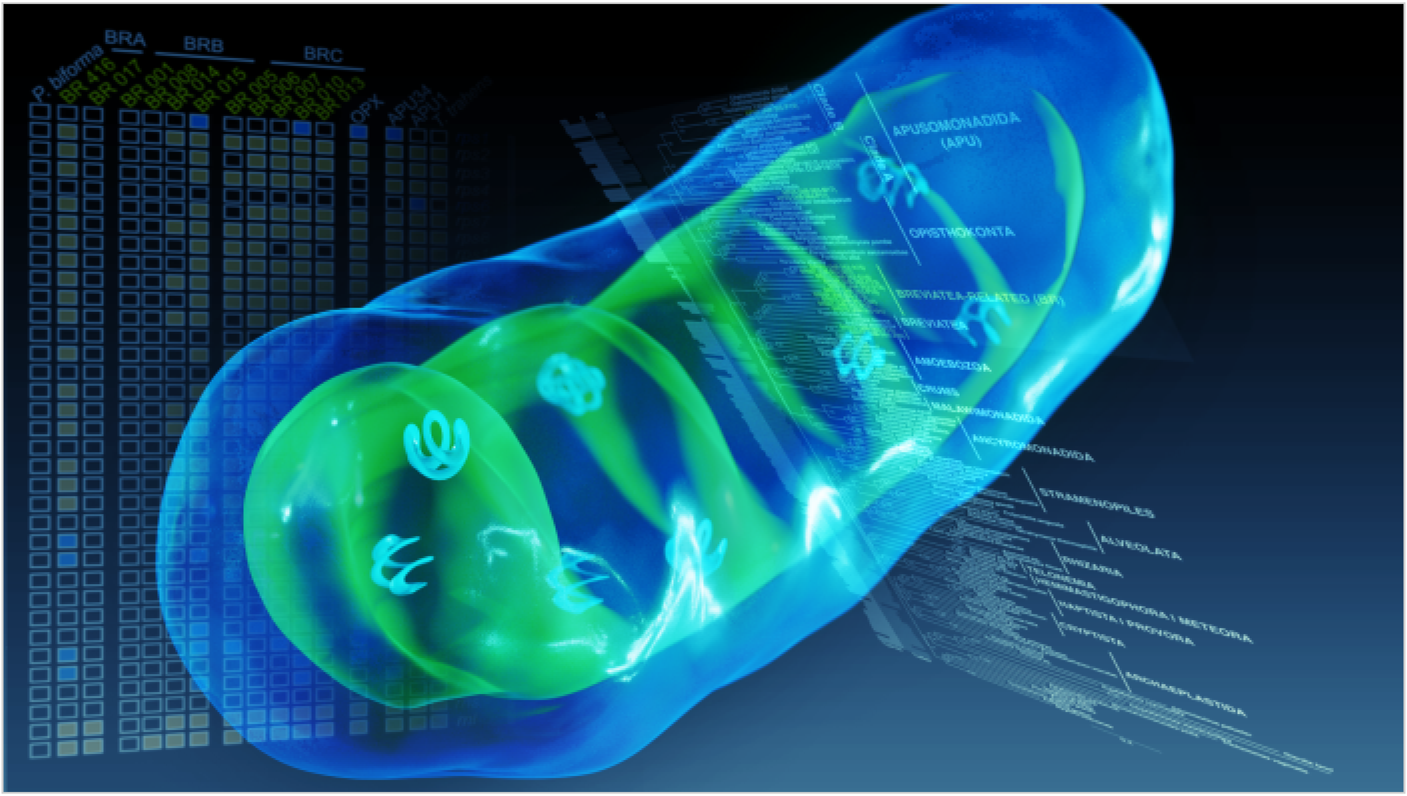
Main image



A newly discovered lineage of microbes is helping scientists understand how mitochondria — the energy-producing structures inside cells — can evolve, shrink or disappear as organisms adapt to low-oxygen environments. Graphic by Jason Drees/ASU

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