Evolution is as complicated as 1-2-3

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EAST LANSING, Mich. — A team of researchers at Michigan State University has documented the step-by-step process in which organisms evolve new functions.

The results, published in the current issue of Nature, are revealed through an in-depth, genomics-based analysis that decodes how E. coli bacteria figured out how to supplement a traditional diet of glucose with an extra course of citrate.

“It’s pretty nifty to see a new biological function evolve,” said Zachary Blount, postdoctoral researcher in MSU’s BEACON Center for the Study of Evolution in Action. “The first citrate-eaters were just barely able to grow on the citrate, but they got much better over time. We wanted to understand the changes that allowed the bacteria to evolve this new ability. We were lucky to have a system that allowed us to do so.”

Normal E. coli can’t digest citrate when oxygen is present. In fact, it’s a distinct hallmark of E. coli. They can’t eat citrate because E. coli don’t express the right protein to absorb citrate molecules.

To decipher the responsible mutations, Blount worked with Richard Lenski, MSU Hannah Distinguished Professor of Microbiology and Molecular Genetics [http://myxo.css.msu.edu/] . Lenski’s long-term experiment, cultivating cultures of fast-growing E. coli, was launched in 1988 and has allowed him and his teammates to study more than more than 56,000 generations of bacterial evolution.

The experiment demonstrates natural selection at work. And because samples are frozen and available for later study, when something new emerges scientists can go back to earlier generations to look for the steps that happened along the way.

“We first saw the citrate-using bacteria around 33,000 generations,” Lenski explained. “But Zack was able to show that some of the important mutations had already occurred before then by replaying evolution from different intermediate stages. He showed you could re-evolve the citrate-eaters, but only after some of the other pieces of the puzzle were in place.”

Zachary Blount, postdoctoral researcher in MSU’s BEACON Center for the Study of Evolution in Action, led a team of researchers in documenting the step-by-step process in which organisms evolve new functions. Courtesy of Brian Baer.

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In the Nature paper, Blount and his teammates analyzed 29 genomes from different generations to find the mutational pieces of the puzzle. They uncovered a three-step process in which the bacteria developed this new ability.

The first stage was potentiation, when the E. coli accumulated at least two mutations that set the stage for later events. The second step, actualization, is when the bacteria first began eating citrate, but only just barely nibbling at it. The final stage, refinement, involved mutations that greatly improved the initially weak function. This allowed the citrate eaters to wolf down their new food source and to become dominant in the population.

“We were particularly excited about the actualization stage,” Blount said. “The actual mutation involved is quite complex. It re-arranged part of the bacteria’s DNA, making a new regulatory module that had not existed before. This new module causes the production of a protein that allows the bacteria to bring citrate into the cell when oxygen is present. That is a new trick for E. coli.”

The change was far from normal, Lenski said.

“It wasn’t a typical mutation at all, where just one base-pair, one letter, in the genome is changed,” he said. “Instead, part of the genome was copied so that two chunks of DNA were stitched together in a new way. One chunk encoded a protein to get citrate into the cell, and the other chunk caused that protein to be expressed.”

Additional co-authors include Jeff Barrick, University of Texas, and Carla Davidson, University of Calgary.

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