Evolution can select for evolvability, biologists find

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Evolution does not operate with a goal in mind; it does not have foresight. But organisms that have a greater capacity to evolve may fare better in rapidly changing environments. This raises the question: does evolution favor characteristics that increase a species' ability to evolve?

For several years, biologists have attempted to provide evidence that natural selection has acted on evolvability. Now a new paper by University of Pennsylvania researchers offers, for the first time, clear evidence that the answer is yes.

The senior author on the study, published in the journal *PLOS Pathogens*, is Dustin Brisson, an assistant professor in the School of Arts and Sciences' Department of Biology. His coauthors include Penn's Christopher J. Graves, Vera I. D. Ros and Paul D. Sniegowski, and the University of Kentucky's Brian Stevenson.

"It's not controversial that populations evolve and that some traits are more apt to evolve than others," Brisson said. "What we were asking is whether the ability of an organism to evolve is a trait that natural selection can pick."

For species of viruses, pathogenic bacteria and parasites to survive over the long-term, they must possess an ability to rapidly adapt and evolve, enabling them to stay one step ahead of their hosts' immune systems. But these pathogens don't need to foresee what conditions lie ahead of them. They only must change into something that the immune system has never

seen before.

"Pathogens face a very strong selection pressure from the host's immune system," Brisson said. "If they don't adapt, they will die."

The researchers used this fact to seek evidence that natural selection had favored increased evolvability, focusing on the Lyme disease bacteria, *Borrelia burgdorferi*.

B. burgdorferi possesses one protein that is essential for establishing a long-term infection of a mammalian host: VlsE.

In the Lyme bacteria's genome, the VlsE gene is preceded by "cassettes" which are normally not expressed, or made into individual proteins, but can recombine with VlsE to alter the expressed protein and thus present a novel challenge to a host's immune defenses.

Though earlier studies had suggested that selection may directly favor the capacity to evolve, they could not definitively rule out that evolvability had arisen for other reasons. In particular, it has been difficult in empirical studies to rule out the possibility that evolvability arises and is maintained as a byproduct of selection on organismal features more directly related to fitness.

In the Lyme disease system, the researchers got around this confounding factor by looking at diversity in the unexpressed cassettes, which would not have been the object of direct selection because they have no known function on their own; they simply exist as a way of increasing the potential diversity of the VlsE protein. Thus diversity in the cassettes would offer a window into past natural selection for a more "evolvable" VlsE.

"Organisms with greater diversity among the cassettes will have a

selective advantage as they will be more antigenically evolvable, or better able to repeatedly generate novel antigens, and will thus be more likely to persist within hosts," the researchers wrote.

Using long-established methods in molecular evolution, the researchers evaluated 12 strains of *B. burgdorferi* for signs that natural selection had acted to increase the diversity of the cassettes.

"The evidence was remarkably strong in favor of evolution for more diversity among cassettes and thus greater evolvability in the expressed protein," Brisson said.

The researchers confirmed that the more genetically diverse the cassettes, the more genetically diverse the expressed protein, VlsE. They also found that mutations in the cassettes that could affect the portion of VlsE that is recognized by the immune system were as much as eight times more common than would be expected by chance alone and more common than mutations that affected other parts of the VlsE protein. In addition, the rate of mutation at the unexpressed cassettes was greater than that at other locations in the bacterial genome.

Taken together, the results provide direct evidence that evolvability was the target of natural selection. The researchers note, however, that this doesn't mean that "natural selection for evolvability" is necessarily a common trait across all living things.

"It would be incredibly difficult to demonstrate this for free-living eukaryotic organisms, like humans," Brisson said. "But we can now say that evolvability can be the object of selection in the face of environmental pressure."

Provided by University of Pennsylvania