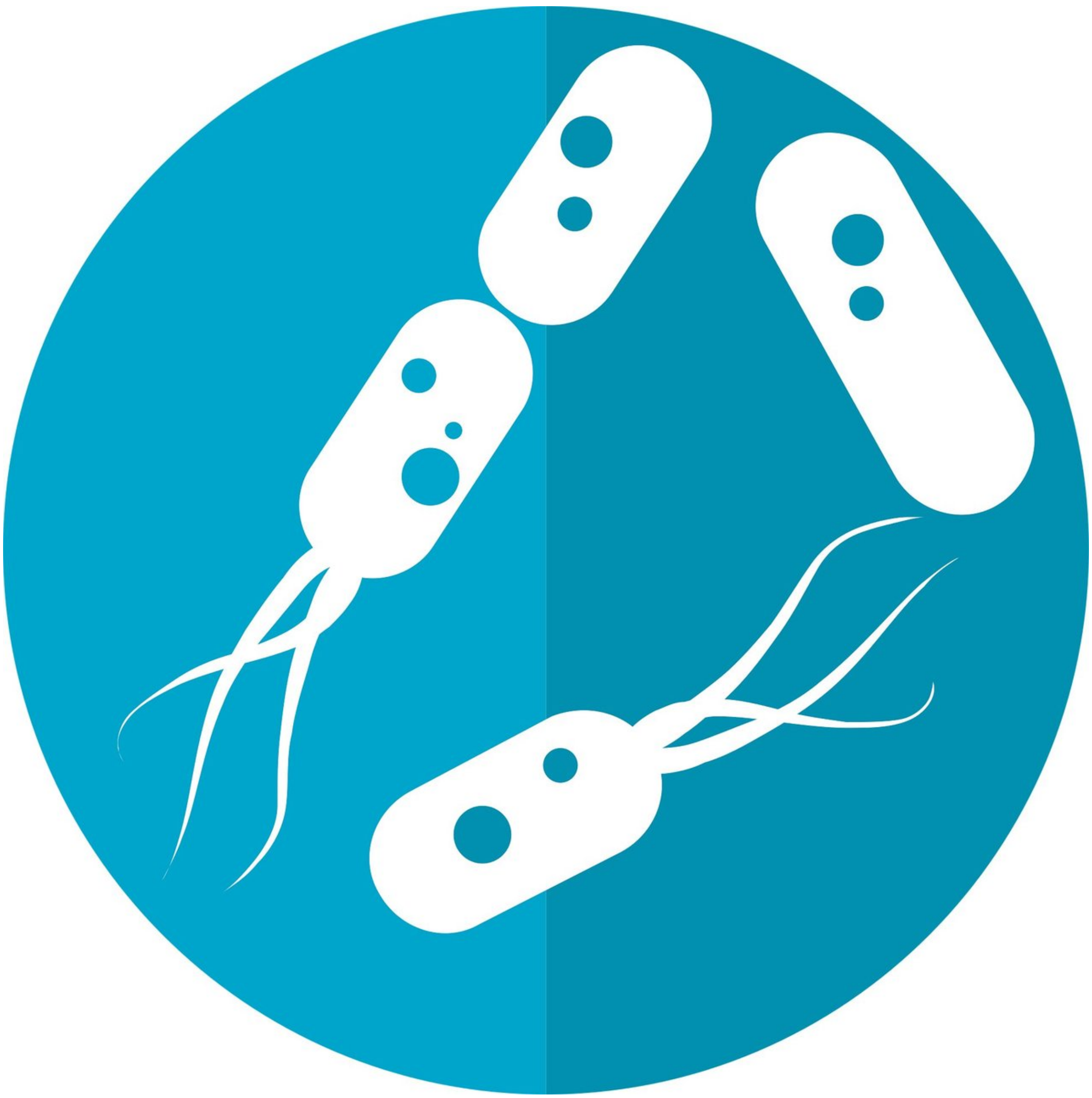
Dynamics of gut bacteria follow ecological laws

May 13 2020



The seemingly chaotic bacterial soup of the gut microbiome is more organized than it first appears and follows some of the same ecological laws that apply to birds, fish, tropical rainforests, and even complex economic and financial markets, according to a new paper in *Nature Microbiology* by researchers at Columbia University Irving Medical Center.

One of the main challenges facing researchers who study the gut microbiome is its sheer size and amazing organizational complexity. Many trillions of bacteria, representing thousands of different species, live in the human intestinal tract, interacting with each other and the environment in countless and constantly changing ways.

The study's discovery of multiple principles of gut bacterial dynamics should help researchers to understand what makes a gut microbiome healthy, how it may become perturbed in disease and unhealthy diets, and also suggest ways we could alter microbiomes to improve health.

Gut microbiome dynamics remain poorly understood

Although current DNA sequencing technologies make it possible to identify and track bacteria in the gut over time, "the biological processes governing the short- and long-term changes in the gut's microbiome remain very poorly understood," says the study's senior author, Dennis Vitkup, Ph.D., associate professor of systems biology and of biomedical informatics at Columbia University Vagelos College of Physicians and Surgeons.

As a first step in identifying the factors that describe microbial communities in the gut, Vitkup and his co-authors, graduate students Brian W. Ji and Ravi U. Sheth and research scientists Purushottam Dixit and Konstantine Tchourine, looked for mathematical relationships describing dynamical changes of the gut microbiome of four healthy people followed for a year. They also analyzed microbiome data obtained for mice fed either high fiber or high fat diets every day for several weeks.

With this data, the researchers explored statistical connections between various aspects of microbiome dynamics, such as fluctuations and abundances of various bacteria over time, or the average times different microbes continuously reside in the human gut. "Up to now, it has been an open question whether there are any natural laws describing dynamics of these complex bacterial communities," Vitkup says.

Chaotic fluctuations follow statistical laws

As expected, they discovered large fluctuations in the composition and daily changes of the human and mouse gut microbiomes. But strikingly, these apparently chaotic fluctuations followed several elegant ecological laws.

"Similar to many animal ecologies and complex financial markets, a healthy gut microbiome is never truly at equilibrium," Vitkup says. "For example, the number of a particular bacterial species on day one is never the same on day two, and so on. It constantly fluctuates, like stocks in a financial market or number of animals in a valley, but these fluctuations are not arbitrary. In fact, they follow predictable patterns described by Taylor's power law, a well-established principle in animal ecology that describe how fluctuations are related to the relative number of bacteria for different species."

Other discovered laws of the gut microbiome also followed principles frequently observed in animal ecologies and economic systems, including the tendency of gut bacteria abundances to slowly but predictably drift over time and the tendency of species to appear and disappear from the gut microbiome at predictable times.

"It is amazing that microscopic biological communities—which are about six orders of magnitude smaller than macroscopic ecosystems analyzed previously—appear to be governed by a similar set of mathematical and statistical principles," says Vitkup.

Laws allow identification of abnormal bacterial behavior

These universal principles should help researchers to better understand what processes govern the microbial dynamics in the gut. Using the statistical laws, the Columbia researchers were able to identify particular bacterial species with abnormal fluctuations. These wildly fluctuating bacteria were associated with documented periods of gut distress or travel to foreign countries in humans providing data for the study. Thus, this approach may immediately allow researchers to understand and identify which specific bacteria are out of line and behave in a potentially harmful fashion.

Using mice data, the researchers also observed that microbiomes associated with unhealthy high fat diets drift in time significantly faster compared with microbiomes feeding on healthier high fiber diets. This demonstrates that ecological laws can be applied to understand how various dietary changes may affect and perhaps alleviate persistent microbiome instabilities.

Gut microbiome as miniature ecological laboratory

The study by Columbia researchers also opens an exciting opportunity to use the gut microbial communities as a model system for exploring general ecological relationships. "Ecologists have debated for years why and how these natural ecological laws arise, without any clear answers," says Vitkup. "Previous ecological research has been mostly limited to observational studies, which can take decades to perform for animals and plants. And some key experiments, such as additions or removal of particular species simply cannot be performed."

The gut microbiome, in contrast, provides an ideal miniature laboratory, where researchers could easily manipulate different variables, such as the number and composition of microorganisms, and then explore various aspects of environmental influences. "One of our next goals is to understand the origin of these general ecological laws using gut microbiota," Vitkup says.

More information: Brian W. Ji et al, Macroecological dynamics of gut microbiota, *Nature Microbiology* (2020). DOI: 10.1038/s41564-020-0685-1

Provided by Columbia University Irving Medical Center