Space Life Sciences Research Highlights

“Observing” Microorganisms on ISS Leads to a Novel Understanding of Life on Earth

By using the ISS research platform as a Microbial Observatory, scientists are profoundly challenging their perception of how microorganisms respond to the spaceflight environment over long term habitation. By understanding how microbes adapt to this extreme environment, we are gaining knowledge into how microorganisms interact with each other, cause disease, and promote health. This provides benefits here on Earth and is critical to improving safety and sustainability for life in future long duration space exploration missions.

Along with each human who travels into space go around 100 million million (10^{14}) other organisms that are part of the human microbiome. While equipment and supplies can be sanitized and even sterilized, the organisms that are part of the human microbiome are inseparable from their host. Although the skin and mucous membranes of humans harbor large numbers of bacteria, viruses, and other microbes, the gut is where the largest numbers and variety of microbes are found. Many of the microbes are critical to the wellbeing of their person. In fact, altered microbial community profiles are associated with a variety of chronic diseases such as inflammatory bowel disease, allergic conditions, obesity, and psychiatric and neurological disorders (1-3). Others are benign and are present because the person’s metabolism provides the microbes with sustenance and a welcoming environment in which to live. Still others can be harmful to their human host.

Astronaut Heidemarie M. Stefanyshyn-Piper activating the MICROBE experiment investigating Salmonella typhiumurium *virulence and gene expression during Expedition 13/STS-115 joint operations (NASA Photo s115e07274)*

Immunization and careful screening of crew-members before a spaceflight can greatly decrease the more serious pathogens. However, opportunistic organisms can create serious problems for the crew when they become pathogenic after periods, often very long ones, of benign coexistence. Because of the large inoculum created by humans, most surfaces within the spacecraft, like surfaces in buildings, rapidly become covered with microbes that cohabit with the crew. On Earth’s surface, the natural outdoor environment has its own rich diversity of microbes, many of which also colonize building interiors. These organisms likely limit the “foothold” that human associated microbes can achieve. On the International Space Station (ISS), that environmental input is eliminated or much reduced.

Furthermore, as exploration missions move further and further away from low-Earth orbit, biology will play larger, essential roles in life support for the crew. Growth of plants for generation of O_2, purified water, and nutrition for the astronauts will be accompanied by microbes. Reactors for converting waste materials (from plants, animals, and humans) into substances necessary to propagate those plants successfully will be important parts of engineered spacecraft ecosystems.

Because of the ubiquity of microbes in crewed capsules now and into the future, it is essential to understand the organisms’ behavior in space to avoid harmful effects to the crew and equipment within the spacecraft, and whenever possible to exploit their abilities to accomplish critical elements that cannot be done practically by other approaches.

Novel Microbial Responses to the Unique Environment

Since the early days of the spaceflight program, experiments have demonstrated that microorganisms grown in the space environment often exhibit significantly different responses (4). Early work found that many microorganisms can grow to greater cell concentrations, change their morphology, and resist being killed by antibiotic concentrations that kill them on Earth. These studies informed the way NASA addressed microbiological questions in the design of spacecraft and medical operational activities with the crew.

Research on robotic satellites, Apollo 16-17, MIR, and Space Shuttle provided greater detail into how microorganisms responded to spaceflight (5). Targeted research using *Escherichia coli* focused on the cell concentration throughout its growth cycle and differences between cultures grown during spaceflight and in ground controls. The lag phase was shortened, the exponential growth phase was extended, and the bacterial cell populations were 88% greater than those of ground controls (6).

On ISS, better analytical tools and increased access to spaceflight provide new insight that not only benefits the humans in space but also the general population on Earth. Investigations into the disease causing potential and/or changes in gene expression of disease-causing microorganisms have given us novel insight into how these organisms infect and modify response to changes in the environment (7-10). Other researchers investigated the effects of microgravity on the growth, cellular physiology, and cell-cell interactions in microbial biofilms created by *P. aeruginosa* and *Staphylococcus aureus* (10, 11). Collectively, these experiments provide a deeper understanding of the response of medically significant microorganisms to spaceflight culture and an increased ability to translate those findings toward a better understanding of those organisms on Earth.

WHAT IS NASA DOING ON ISS?

NASA has designated ISS as a microbial observatory and regularly solicits investigator-initiated research proposals to characterize the effects of space flight on microorganisms. Funded experiments are designed to determine 1) genetic/genomic/physiological responses of specific microbes; 2) how communities of microbes are structured in the absence of frequent importation of new community members or replenishment of those already present; and 3) how communities of microbes evolve over time in space. Approaches may be experimental (manipulation of organisms or conditions to elicit a response) or observational (e.g., inventories of microbes present and their distribution). The unique characteristics of the ISS—the isolated, human dominated system, in microgravity and above Earth's atmosphere—make it an important resource in which to study properties of microbes and their communities, and responses to spaceflight that cannot be examined on Earth.

Understanding Microbial Interaction with Humans, Plants, and Each Other

Communication panel aboard the Mir Space Station which lost function due to biodegradation by a fungal contaminant.

Because multiple types of microbes will always be a part of any human exploration mission, it is essential to know, not only how individual microbes cope with spaceflight, but also how spaceflight conditions affects microbial interactions among themselves, among the other living beings that share the habitat, and with the structures and systems which they inhabit. The ubiquity of microorganisms in close association with all living things and biogeochemical processes on Earth predicates that they must also play a critical role in maintaining the viability of human life in space during long-term missions isolated from Earth resources for periods up to several years. Sustainable plant growth and resource recovery from wastes are necessary to permit such missions, and these systems inherently depend on microbes for their efficacy. The local species richness of microbial communities in space is relatively low because of sterilization of materials prior to launch and physical barriers between Earth and spacecraft after launch. While community diversity may be sufficient to sustain minimal ecosystem functions at the obset, diversity may decline over time such that systems either lose function (e.g., bioreactors may fail to reduce biochemical oxygen demand or nitrogen load) or become susceptible to invasion by human-associated microorganisms (opportunistic pathogens). ISS provides a unique opportunity to study the behavior of microbes in combinations that might be important in promoting plant growth or protecting plants from opportunistic plant pathogens, that might arise similar to what has been seen with human-associated microbes. In previous flight experiments, biofilms developed differently in spaceflight conditions than on Earth's surface, biofilms were thicker and denser and developed a novel column-and-canopy structure that has not been observed on Earth (11).

We can study important ecological questions such as community convergence in isolated conditions, and develop strategies to maintain community stability for long periods of time in a system in which selective pressures and limited ecological niches tend to reduce diversity. Important changes in community structure might come about through crew changes (e.g., an individual carrying an organism that might negatively disrupt the indigenous community), a failure to sterilize successfully supplies or equipment (i.e., a stowaway), or an alteration of a benign member of the community through mutation to a form that either causes some undesirable effect, or reduces the capacity of the community to withstand invasion from one of the undesirable types being held at bay by the community.

For all these reasons, microbes are destined ultimately to play critical roles in life support during extended human missions and it has been proposed that their study should be an integral component of the expansion of humankind throughout the Solar System as NASA carries out US Space Policy over the centuries (12).

References

1. Gevers D, Kugathasan S, Denson LA, Vázquez-Baeza Y, Van Treuren W, Ren B, . . . Xavier RJ. The treatment-naive microbiome in new-onset Crohn's disease. Cell Host Microbe. 2014 Mar 12;15(3):382-92.
2. Marietta EV, David CS, Murray JA. Important lessons derived from animal models of celiac disease. Int Rev Immunol. 2011 Aug;30(4):197-206.
3. Collins SM, Bercik P. Gut microbiota: Intestinal bacteria influence brain activity in healthy humans. Nat Rev Gastroenterol Hepatol. 2013 Jun;10(6):326-7.
4. Dickson KJ. Summary of biological spaceflight experiments with cells. ASGSB Bull. 1991 Jul;4(2):151-260.
5. Horneck G, Klaus DM, Mancinelli RL. Space microbiology. Microbiol Mol Biol Rev. 2010 Mar;74(1):121-56.
6. Klaus D, Simske S, Todd P, Stodieck L. Investigation of space flight effects on *Escherichia coli* and a proposed model of underlying physical mechanisms. Microbiology. 1997 Feb;143 (Pt 2):449-55.
7. Wilson JW, Ott CM, Höner zu Bentrup K, Ramamurthy R, Quick L, Porwollik S, . . . Nickerson CA. Space flight alters bacterial gene expression and virulence and reveals a role for global regulator Hfq. Proc Natl Acad Sci U S A. 2007 Oct 9;104(41):16299-304
8. Wilson JW, Ott CM, Quick L, Davis R, Höner zu Bentrup K, Crabbé A, . . . Nickerson CA. Media ion composition controls regulatory and virulence response of *Salmonella* in spaceflight. PLoS One. 2008;3(12):e3923.
9. Crabbé A, Schurr MJ, Monsieurs P, Morici L, Schurr J, Wilson JW, . . . Nickerson CA. Transcriptional and proteomic responses of *Pseudomonas aeruginosa* PAO1 to spaceflight conditions involve Hfq regulation and reveal a role for oxygen. Appl Environ Microbiol. 2011 Feb;77(4):1221-30.
10. Crabbé A, Nielsen-Preiss SM, Woolley CM, Barrila J, Buchanan K, McCracken J, . . . Nickerson CA. Spaceflight enhances cell aggregation and random budding in *Candida albicans*. PLoS One. 2013 Dec 4;8(12):e80677.
11. Kim W, Tengra FK, Young Z, Shong J, Marchand N, Chan HK, . . . Collins CH. Spaceflight promotes biofilm formation by *Pseudomonas aeruginosa*. PLoS One. 2013 Apr 29;8(4):e62437.
12. Des Marais DJ, Nuth JA 3rd, Allamandola LJ, Boss AP, Farmer JD, Hoehler TM, . . . Spormann AM. The NASA Astrobiology Roadmap. Astrobiology. 2008 Aug;8(4):715-30.

For additional information, contact: Space Life and Physical Sciences Research and Applications Division,
National Aeronautics and Space Administration *http://www.nasa.gov/directorates/heo/slpsra/*

May 2015