Expect the unexpected in space microbiology

Crewed missions to other planets are currently being planned, and fully automated, robotic missions are likely to return samples from other planets to Earth, so it will be important to carefully evaluate and minimize any associated microbiological risks.

Microorganisms have inhabited Earth for billions of years and have evolved to thrive in seemingly inhospitable environments. For example, some hyperthermophilic archaea can grow up to a temperature of 122 °C (*Methanopyrus kandleri*)[1] and some can survive up to 130 °C (*Geogemma barossii*)[2]. Life in such hostile conditions was presumed to be unlikely just a few decades ago. Other microorganisms have adapted to life in the cold. For example, *Planococcus halocryophilus* OR1 grows at −15 °C (ref. [3]), and *Deinococcus geothermalis* can grow at temperatures as low as −25 °C (ref. [4]). Extremophilic microorganisms can also withstand radiation. One study examined how *Deinococcus* spp. respond to exposure to conditions outside the International Space Station (ISS), and found that aggregated cells of *Deinococcus radiodurans* tolerated radiation levels more than 200 times those that are present on Earth, and survived 3 years of exposure in space[5].

The ability of microorganisms to tolerate harsh conditions on Earth makes it important to consider whether microorganisms can live in space, and whether space missions that transport humans to other planets, or moons, need to make microbiological risk assessments. For starters, astronauts will transport their own microbiota into space, including the microorganisms on their skin, in their guts, or those that they exhale. Human-associated microbiomes are with us for life and it is neither easy nor desirable to remove them. Any plants and insects taken on board would also harbour their own microbial passengers. All off-planet expeditions must therefore consider unintentional microbial contamination of space vessels and extraterrestrial locations. Of course, microorganisms from human, animal, plant or insect microbiomes may not be resistant to radiation, or grow in microgravity, but potential risks should be evaluated. Two Comments in this issue of *Nature Microbiology* address these issues in detail.

In a Comment, Andy Spry, who was the planetary protection manager and aseptic assembly facility manager for the European Space Agency Beagle 2 mission in 2003 before taking on his current role at the SETI Institute as consultant to the NASA planetary protection officer, discusses live issues in planetary protection, which is defined as the control of the spread of terrestrial microbial contamination into that environment. Planetary protection is managed by the Committee on Space Research (COSPAR), on behalf of the United Nations. COSPAR has categorized Solar System bodies depending on their degree of Earth-like conditions according to levels of solar radiation, gravity, atmospheric pressure, magnetic fields and temperature. Based on this information, Mars, and the moons Europa and Enceladus, are thought to be the most habitable places in our Solar System, and would hence be at the highest risk of being contaminated by terrestrial microorganisms, also known as 'forward contamination'. It is formally possible that life has independently evolved on extraterrestrial planets and moons, and 'backward contamination' would describe any case in which alien microorganisms are inadvertently brought back to contaminate Earth.

Another type of backward contamination might arise if astronauts' own microbiota, or microorganisms on the surfaces of space ships or space stations, such as the ISS, evolve off-planet, and re-infect astronauts to cause disease[6]. One study found that clinically relevant environmental bacteria can grow on carbohydrates from carbonaceous meteorites, and that this can impact pathogenicity[7]. A more recent study[8] sampled surfaces from the ISS and reported that ISS-associated microbiomes are similar to those present on Earth. The authors concluded that "the ISS environment supports selection of the best-adapted microorganisms (e.g., spore-formers) toward the partially extreme physical and chemical environmental conditions (e.g., radiation, alkaline cleaning agents), but does not induce permanent changes in the physiological nor genomic capacities of microbes."

Approaches to minimize risks of backward contamination could include quarantining returning astronauts for several weeks or months, and rigorous health checks to assess any potential contamination threats.

A second Comment from Cheryl Nickerson, Mark Ott and colleagues discusses the human health and habitat sustainability aspects of spaceflight microbiology, and argues that microorganisms will have a crucial role in astronaut health, habitat sustainability and overall mission success. Before a space mission, astronaut crew undergo a pre-flight quarantine, and the spacecraft, cargo and food are monitored for microorganisms. Despite these efforts, astronauts have suffered infections. Take the case of the Apollo 7 mission in 1968, in which crew suffered from bacterial or viral infections during or after the space mission[6,9]. It is near impossible to avoid transfer of potentially infectious microorganisms to space vessels and studies characterizing the microbiome of the ISS have detected diverse bacteria and fungi[10], including pathogenic species. *Salmonella* species have been isolated from space shuttles and the ISS, and experiments have shown that *Salmonella* cultured on board the ISS exhibited higher virulence in a mouse model of infection[11]. Experiments are therefore important to understand the potential microbiological risks that crew members are exposed to, and they are currently being performed on board the ISS. For the interested reader, we refer to an interview with NASA astronaut Kate Rubins on her preparation for and time on board the ISS, including the microbiology experiments that she carried out in space[12].

Terrestrial microorganisms have tremendous potential to evolve and adapt to life in various niches, including those off-planet, and besides all the current safety procedures of sterilization, quarantine and astronaut health checks, it is important not to underestimate evolution, and to expect the unexpected.

Research into microbial life in the most extreme, inhospitable biomes on Earth, such as that carried out in the Extreme Microbiome Project, which has optimized methods for these microorganisms and samples, will form a much-needed knowledge base for understanding the features microorganisms need to survive in extraterrestrial environments or space. Together with ongoing efforts to address how terrestrial microorganisms behave in space, research will be key to better understanding any microbiological risks posed by venturing out beyond the bounds of our planet. ❐

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