Gut Check at the Extremes: Microbiome in Space and Expeditionary Medicine and Role of Probiotics

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INTRODUCTION

The **human microbiome** functions as a dynamic, adaptive "**invisible organ**."

Plays a key role in:
- **Immune regulation**
- **Nutrient absorption and metabolism**
- **Gastrointestinal stability**
- **Cognitive and mood balance**

Microbiome Sensitivity
Unlike other organ systems, the microbiome is **highly responsive to environmental stressors**.
Acts as an early indicator of **physiologic resilience or vulnerability** under stress.

Extreme Environments as Natural Laboratories

Spaceflight, **Antarctic overwintering**, **submarine missions**, and **high-altitude expeditions** serve as unique models.
These settings share key stressors:
Isolation and confinement
Restricted diet and limited fresh food
Altered circadian rhythm and light exposure
Environmental extremes (microgravity, hypoxia, cold)

Rationale for Investigation
Understanding how **environmental stress affects the microbiome** provides insight into human adaptation and health in extreme conditions. Exploring **microbiome-targeted interventions** (nutrition, pre/probiotics, habitat design) may enhance **resilience and mission success**.

METHODS

A literature search was conducted using PubMed, Scopus, and Web of Science (2000–2024). Keywords included *microbiome, probiotics, spaceflight, astronauts, Antarctic, high altitude, submarine, expedition medicine, ICU*. Studies were included if they evaluated microbiome alterations in extreme environments or tested probiotic interventions relevant to expeditionary or space medicine. Both human and relevant animal studies were included.

FIGURE 1: Hexagonal radial diagram illustrating how diverse extreme environments converge on similar patterns of microbiome change.

RESULTS

Spaceflight Evidence
NASA Twins Study - Identified transient shifts in gut microbiota with immune changes and systemic inflammation (1)
Astronaut Microbiome Project Reported reduced gut and skin microbial diversity; associated with increased susceptibility to skin irritation and GI symptoms (2)
JAXA Probiotic Pilot: *Lactobacillus casei Shirota* supplementation in astronauts was safe, remained viable in orbit, and stabilized some immune markers.(3)
Antarctic & Polar Expeditions
Winter-over crews demonstrated reduced gut microbial diversity, immune suppression, and mood changes. Probiotics proposed but not yet systematically tested.(4)
High-Altitude Environments
Mountaineers displayed shifts in short-chain fatty acid (SCFA)-producing microbes under hypoxia. Small trials suggested probiotics improved gastrointestinal tolerance and reduced symptoms of altitude-related gut distress.(5)

Closed Habitats (Submarines, Confined Crews
Microbiomes of submarines and ISS crews show parallels: restricted microbial turnover, reduced diversity, and enrichment of resistant organisms. (6)

DISCUSSION

Key Patterns
Across all environments, consistent **microbiome dysbiosis** observed: (see figure 1)
↓ **Diversity**
↑ **Opportunistic pathogens**
↓ **Functional stability**

Dysbiosis contributes to:
Immune weakness and inflammation
Nutrient malabsorption
Neurobehavioral stress
Reduced performance and resilience

Probiotics as a Countermeasure
Immune Support: Stabilizes **NK cell activity** and **cytokine balance** (space and ICU parallels).
Gastrointestinal Protection: Decreases **diarrhea** and improves **gut comfort** under stress.

Feasibility:
Certain strains remain **stable in orbit**.
Freeze-dried formulations practical for expeditions and long missions.

Limitations & Gaps
Strain-specific effects; benefits not generalizable across all probiotics.
Small-scale pilot studies dominate current evidence.
Operational challenges: long-term **storage**, **compliance**, and **formulation stability** for extended missions.

CONCLUSIONS

Microbiome disruption is a **shared physiological vulnerability** across spaceflight and terrestrial extremes.
•**Probiotics** offer a **biologically plausible, low-risk, and feasible** countermeasure to maintain microbial and immune stability.
•Current data support **cautious integration** into expeditionary and space medicine protocols.
•The key question is evolving from:
"**If** probiotics work" → to "**Which** probiotics, for **which** environment, and **when** should they be deployed?"
Protecting the microbiome may be **central to human resilience and mission success** in extreme environments.

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