Probiotics in the Space Food System: Delivery, Microgravity Effects, and the Potential Benefit to Crew Health

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Influences are Environment, stress, mood, and health:
- Microgravity
- Sleep shift
- Temperature
- Air Quality
- Light
- Exercise
- Antibiotics/Meds
- Pathogens

**FOOD**

**EFFECTS:** Cardiovascular, bone, muscle, behavioral health and performance, immune response, etc.
Probiotics

- Why?
  - Why probiotics?
- How?
  - How do we deliver probiotics in spaceflight?
  - How do probiotics respond to microgravity?
- What?
  - What is the human response to probiotics in microgravity?
WHY: Probiotics?

HUMAN STATE IN SPACEFLIGHT

- Stress, Anxiety, Depression (Slack et al. 2009)
- Elevated inflammatory cytokines (Crucian et al. 2014)
- Reduced immune cell function (Crucian et al. 2008)

POSSIBLE OUTCOMES

- Withdrawal, Conflict
- Major Psychological Event
- Illness
- Performance Decrement

NEED FOR NONINVASIVE COUNTERMEASURES
Lactobacilli and health

1907
Elie Metchnikoff publishes *The Prolongation of Life: Optimistic Studies.*

1915
Leo Rettger proposes *L. acidophilus* as a suitable probiotic.

1930
Minoru Shirota isolates *L. casei,* develops and commercializes Yakult.

1950+
Techniques developed enabling genomic elucidation of probiotic mechanisms.

2010
Human gut microbiome catalogued.
Probiotics are “live microorganisms which when administered in adequate amounts confer a health benefit on the host” (WHO/FAO)

<table>
<thead>
<tr>
<th>Probiotic-Associated Benefit</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Protection against infection</td>
<td>Corr et al. (2007)</td>
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<tr>
<td>Lowered incidence of diarrhea</td>
<td>Leyer et al. (2009)</td>
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<tr>
<td>Lowered risk of antibiotic-associated diarrhea</td>
<td>Gao et al. (2010)</td>
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<tr>
<td>Lowered levels of cold and influenza-like symptoms</td>
<td>Leyer et al. (2009)</td>
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<td>Inhibition of H. pylori</td>
<td>Fujimura et al. (2012)</td>
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<td>Prevention of upper respiratory infection</td>
<td>Hao et al. (2011)</td>
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<td>Return to pre-antibiotic baseline flora</td>
<td>Engelbrektson et al. (2009)</td>
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<tr>
<td>Epithelial barrier function</td>
<td>Mennigen and Bruewer (2009)</td>
</tr>
<tr>
<td>Increased humoral Immunity via secretion of IgA</td>
<td>Viljanen et al. (2005)</td>
</tr>
<tr>
<td>Competitive exclusion of pathogens</td>
<td>Lee et al. (2003)</td>
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<tr>
<td>Neuroactive compound production</td>
<td>Wall et al. (2014)</td>
</tr>
<tr>
<td>Reduced psychological distress</td>
<td>Messaoudi et al. (2011)</td>
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<tr>
<td>Reduced anxiety</td>
<td>Rao et al. (2009)</td>
</tr>
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Modified from O’Flaherty and Klaenhammer, 2010
Probiotic Mechanisms

Dinan and Cryan, 2013

Modified from Selle and Klaenhammer, 2013
HOW: deliver within Food System Constraints

Mars Expedition Scenario:
- 2.5 year mission
- Microgravity and reduced gravity
- No resupply
- Food may be prepositioned (5 year shelf life)
- Constrained mass and volume

Within this scenario, probiotics must:
- Survive
- Maintain probiotic attributes
- Provide similar benefits as those recorded on Earth
Probiotic Survival

**CAPSULE** VS **FOOD**

**ROOM TEMPERATURE STORAGE** VS **COLD STORAGE**

**SURVIVAL THROUGH DIGESTIVE TRACT**

pH 2, pepsin VS pH 8, pancreatic juice
Stability of Commercially Available Probiotic

Nonfat Dry Milk as a Delivery Vehicle

![Graph showing survival of probiotics over time in different delivery vehicles.]
Storage Temperature

Eight Months of Storage

PBS

Milk

T₀  22°  4°  -80°  T₀  22°  4°  -80°

Survival (CFU)

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HOW: Respond to Microgravity

Rotating-wall vessel (RWV)
Synthecon (Houston, TX)

LSMMG Orientation

Control Orientation

orbit path of cell
sedimentation effect
solid body rotation of the media
Microgravity Response

- Effect on survival in simulated GI conditions
- Effect on growth
- Effect on gene expression

Illumina MiSeq
Acknowledgments

- Sarah Castro, Ph.D.
- Mark Ott, Ph.D.
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- Microbiology Laboratory
Questions
Probiotic Mechanisms

Probiotic bacteria

Naïve T-cell

AG and co-stimulatory molecules

Dendritic cell (DC)

M cell

TNF-α

IL-12

IL-10

IL-6

Modulate responses

IL-4

IL-10

T_{H1}

T_{H2}

T_{Reg}

Homeostasis

IFN-γ

IL-2

IL-12