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Nutrition and Space Flight

Research DPG

Disclosure: No Conflicts of Interest
Physiological Adaptations to Spaceflight

Psychological/Behavioral/Performance

Neurosensorial adaptations

Cardiovascular adaptations

Fluid shifts, hematological changes

Musculoskeletal changes

Gastrointestinal alterations

Taste and odor sensitivity
ENERGY intake  ENERGY utilization
Energy Intake and Expenditure

Energy Intakes Blue
Expenditure Red

Energy Kcal/day

Energy Intake and Expenditure for various space missions:
- Voskhod
- Gemini, n=6
- Salyut, n=2
- Skylab, n=3
- Skylab, n=3
- Skylab, n=3
- Space Shuttle, n=21
- Space Shuttle, n=13
Energy Intake per Program

- Gemini, n=6
- Salyut, n=2
- Skylab, n=3
- Skylab, n=3
- Skylab, n=3
- Space Shuttle, n=21
- Space Shuttle, n=13
- ISS, E1-4
- ISS E5-16
- ISS E17-20
Space shuttle flights, $O_2$ consumption as $l/min$ measured to determine fitness - oxygen consumption per standard exercise level: 5 subjects during space shuttle flight.

<table>
<thead>
<tr>
<th></th>
<th>Preflight</th>
<th>In-flight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.05 ± 0.12</td>
<td>1.86 ± 0.12</td>
</tr>
</tbody>
</table>

Was there a training effect?
Studies on-going
Fluid Balances as ml/day

<table>
<thead>
<tr>
<th>Program</th>
<th>Extracellular Fluids % change</th>
<th>Plasma Volume % change*</th>
<th>Body Mass % change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo</td>
<td>1647 ± 188</td>
<td>-10 to -15</td>
<td>-1 to 5</td>
</tr>
<tr>
<td>Skylab</td>
<td>2829 ± 529</td>
<td>-10 to -17</td>
<td>0 to -1.5</td>
</tr>
<tr>
<td>Shuttle</td>
<td>2223 ± 669</td>
<td>-9 to -10</td>
<td>-4 to -12</td>
</tr>
</tbody>
</table>

Early space flight assumed weigh loss due to fluid balance, primarily a diuresis effect of microgravity.

Research completed by USSR, European, and US to the effect on the cardiovascular system and the orthostatic intolerance that occurs at landing.

Changes in body water, Skylab and Space Shuttle measured in flight.

*Related to the orthostatic intolerance at landing.
Fluid Balances: Why did these changes happen?

Skylab studies provide the best answer: all nine crewmembers excreted less urine, mean 400 ml less per day than preflight and water intake decreased 700 ml/d. Russians and US also showed increase osmolality of in-flight urine. Until the Space Shuttle flight water had to be launched, for some program managers this reduced consumption was a plus.

Water turn over using double label water with 14 shuttle astronauts:

<table>
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<tr>
<td></td>
<td>3768 ± 509 ml/day</td>
<td>2731 ± 607 ml/day</td>
</tr>
</tbody>
</table>

The decreased plasma volume may relate to the changes within the cardiovascular system, with the head ward shifts of fluids during microgravity, regulatory systems may adjust to lower blood volume of space flight. As of yet, except for landing day, this has not cause problems in space flight. However, there are still active questions, esp. for extended durations with many crew members as with ISS.
Protein Requirements

Protein intakes are complicated by early observations that high protein diets maybe related to renal stones. Astronauts consume less than ideal water levels and with the concentrated urines, was there an increase of bone loss and renal stones?
Changes in Muscle Volume

Deconditioned muscles including decreased leg volume due to inability to load muscles in microgravity

<table>
<thead>
<tr>
<th>Muscle</th>
<th>% Change</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R+1</td>
<td>R+15</td>
<td></td>
</tr>
<tr>
<td><strong>Calf</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>-3.9 ± 0.5a</td>
<td>-3.3 ± 1.1b</td>
<td></td>
</tr>
<tr>
<td>Soleus+Gastroc</td>
<td>-6.3 ± 0.6a</td>
<td>-4.4 ± 2.2b</td>
<td></td>
</tr>
<tr>
<td><strong>Thigh</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadriceps</td>
<td>-6.0 ± 1.7b</td>
<td>-3.1 ± 2.3</td>
<td></td>
</tr>
<tr>
<td>Hamstrings</td>
<td>-8.0 ± 0.9a</td>
<td>-4.8 ± 1.3a</td>
<td></td>
</tr>
<tr>
<td><strong>Lumbar</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intrinsic</td>
<td>-10.3 ± 2.4a</td>
<td>-5.9 ± 1.5a</td>
<td></td>
</tr>
<tr>
<td>Psoas</td>
<td>-3.1 ± 1.5</td>
<td>-2.4 ± 1.6</td>
<td></td>
</tr>
</tbody>
</table>

Changes in Muscle Volume of Four Astronauts 1 and 15 Days After an 8-Day Space Shuttle Mission

a$p < 0.05$
bp$ < 0.07$ versus preflight
R = recovery day
% change = flight vs. preflight
Historically, muscle loss was a significant issue for crew members especially after landing.

Both muscle volume, especially in the weight bearing legs and strength decreased with several studies showing changes in the muscle fibers.

**Question:** Can dietary protein and various amino acid supplements prevent some of the muscle losses?

Research by Ferrando and Wolfe demonstrated no long term effect of branch chain amino acids liquid supplement on skeletal-muscle protein balance during supplement using simulated microgravity, bed rest.
Effect of Energy Intake on Protein Synthesis

Protein synthesis decreased as the estimated energy deficit increased after more than 3 months on Mir.

Protein Intake by Program

<table>
<thead>
<tr>
<th>Program</th>
<th>Protein Intake (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo</td>
<td>70-80</td>
</tr>
<tr>
<td>Skylab</td>
<td>120</td>
</tr>
<tr>
<td>Shuttle</td>
<td>60-70</td>
</tr>
<tr>
<td>ISS (E1-4)</td>
<td>90-100</td>
</tr>
<tr>
<td>ISS (E5-16)</td>
<td>100</td>
</tr>
<tr>
<td>ISS (17-29)</td>
<td>90-100</td>
</tr>
</tbody>
</table>
Protein intakes per body weight over different types of Resistive Exercise

Mir is Russian Space Station
iRED is early resistive exercise equipment
IRED is initial resistive exercise equipment
ARED is the resistive exercise equipment now on ISS
Calcium Intakes per Program-years

Calcium intakes per program-years

Ca mg/d

0 200 400 600 800 1000 1200

Apollo 1968-1972
Skylab 1973
Shuttle 1981-2011
ISS(E1-4) 2000-2001
ISS (E5-16) 2002-2007
ISS(E17-29) 2008-2011
Bone Health

Vitamin D status significantly decreases in space flight due to lack of sun.

Measure of Bone resorption increased.

Blood levels of Calcium do not change, but urinary calcium increases.

Interactions of the role of exercise, bone health and adequate nutrition.
Exercise and Body Mass Measurements
Efficacy of Resistive Exercise on Bone Mineral Density (BMD)

Whole Body BMD

% change/month

-1.5 -1.0 -0.5 0.0 0.5

Mir iRED (E1-13) iRED (E14-18) ARED

Smith et al, J Bone Miner Res, in press
Food Preparation and Dietary Monitoring
## Dietary Intakes

In-flight dietary intake on Apollo, Skylab, and Shuttle.

<table>
<thead>
<tr>
<th></th>
<th>Apollo</th>
<th>Skylab</th>
<th>Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein intake, g/d</td>
<td>$76 \pm 19$</td>
<td>$111 \pm 18$</td>
<td>$78 \pm 19$</td>
</tr>
<tr>
<td>Protein intake, % of kcal</td>
<td>$16 \pm 2$</td>
<td>$16 \pm 2$</td>
<td>$15 \pm 2$</td>
</tr>
<tr>
<td>Carbohydrate intake, g/d</td>
<td>$269 \pm 49$</td>
<td>$413 \pm 59$</td>
<td>$304 \pm 67$</td>
</tr>
<tr>
<td>Carbohydrate intake, % of kcal</td>
<td>$58 \pm 7$</td>
<td>$58 \pm 9$</td>
<td>$58 \pm 5$</td>
</tr>
<tr>
<td>Fat intake, g/d</td>
<td>$61 \pm 21$</td>
<td>$83 \pm 14$</td>
<td>$64 \pm 18$</td>
</tr>
<tr>
<td>Fat intake, % of kcal</td>
<td>$29 \pm 6$</td>
<td>$27 \pm 9$</td>
<td>$27 \pm 4$</td>
</tr>
</tbody>
</table>
Modification of Sodium Content - 37% reduction

Shuttle and Early Space Station (ISS) Sodium Levels – 5600 mg/d for typical menu.

Modified 90 foods, thermostabilized and rehydratable of 200 foods.

**Strategy** – use commercial products and reduced Na equivalents or replace Na with other spices.

**Spices** – disodium inosinate, disodium guanylated to increase umami flavor in savory foods. Lemon juice, basil, oregano, sugar, Mrs Dash Fiesta Lime and Mrs Dash Garlic Herb Seasoning.

**Sensory evaluation** completed on all foods to determine acceptability with some needing to be reformulated. Final products all receive high scores on evaluations.
Modification of Sodium Content 40% reduction

ISSUES

Other foods high in sodium including

- Russian – provides half of the ISS foods
- Japanese
- European

Bonus foods to enhance acceptability and personal preferences
International Space Station Foods

U.S. Foods

Russian Foods

International Community
  Japan
  Europeans
  Canada

US Food Stored by boxes as pantry style

Set up as cycle menu 8 day
  Bonus foods – 10%
  Allows crew members to chose their meal combination

Issues – expiration of foods
Foods on ISS
Texas A&M provides Thermostabilized food
Between 1971 and 2011 learned the following:

- Energy intake to meet needs can be achieved, but unless there is good training and available food, it can be a problem.
- There is no evidence to raise protein intakes for the short term flights of less than 2 weeks.
- Weight loss is primarily due to a combination of lower water and energy intakes, but in general weight loss is less than 5% of body weight.
- Weight loss is not due to diuresis or changes in renal or cardiovascular adaptations to space flight.

Questions answered through research on ISS:

- Protein type and quality, is it important?
- Role of protein, minerals, exercise, and calcium on bone health during long duration space flight?
- Are there other medical issues related to diet such as vitamin metabolism, such as one carbon metabolism?
- During ISS, US foods are becoming lower in sodium, will this have any long term health effects?