Space Nutrition

**Nutrient Requirements**
- Energy
- CHO (fiber), Fat, Protein
- Fat-soluble vitamins
- Water-soluble vitamins
- Minerals
- Fluid

**Systems**
- Bone
- Muscle
- Cardio
- Fluid/Electrolyte
- Immunology
- Hematology

**Countermeasures**
- Energy
- Amino acids
- Protein
- Sodium
- Fatty acids
- Antioxidants
- Other

**Vehicle/Mission**
- Duration
- Food System
- Radiation
- EVA
- Schedule

**Energy**

**Energy and Cardio/Ox. Damage**

**Energy and Muscle/Bone**

**Energy**

https://ntrs.nasa.gov/search.jsp?R=20100011381

2019-11-16T07:42:00+00:00Z
**Protein (and muscle)**

**Dietary Protein**

- Protein intake vs. body weight:
  - Graph showing protein intake per kg body weight with data points and error bars.

**Countermeasures**

- Amino Acids

**SLAMMD**

**Nutrition SMO**

- Images of astronauts in space stations with equipment and food.
Muscle Protein

Protein Synthesis ↓ Protein Breakdown ↑

Amino Acids

Amino acid supplementation

Issues:
- Protein synthesis vs. breakdown
- Exercise
- Catabolic effectors (e.g., stress/cortisol, hypocaloric diet, T3)
- Intake (and/or supplement) of control group

Unloading-induced atrophy is a relatively uncomplicated form of muscle loss. Most of the loss of muscle mass during disuse atrophy can be accounted for by a depression in the rate of protein synthesis.

whereas in disease states associated with inflammation (cancer cachexia, AIDS, burns, sepsis, and uremia), there is a procatabolic hormonal and cytokine environment.

...procatabolic hormonal and cytokine environment...

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Inflammation

NF-κB

kB Inhibitor

NF-κB (active)

1 Muscle proteolysis

Protein Synthesis Breakdown

Inflammatory Markers

Inflammatory Markers
It is imperative that these studies include examination of dynamic measures of muscle protein turnover and putative metabolic controllers... unless we have a clear idea of the basic responses to immobilization per se, the effects of such factors will not be easily teased out and therapeutic goals will remain largely unattainable.

Hyper-catabolism

Hyper-catabolic conditions associated with upregulation of the ubiquitin-proteasome system:
- Cancer cachexia (Lurie et al. 2001; Tisdale et al. 2009)
- Cachexia associated with heart failure (Filippatos et al. 2005, Freeman et al. 1998)
- Sepsis (Voisin et al. 1996; Tiao et al. 1994)
- Starvation (Whitehouse, 2001)
- Metabolic acidosis (Mitch et al. 1994)
- Stress/trauma associated with excess glucocorticoids (Wing et al. 1993, Bolli et al. 2000)
- Space flight (Ikegami et al. 2001; Riley et al. 1992)

Omega 3 (n3) Fatty Acids

- Eicosapentaenoic acid (EPA)
  - 20-C, omega-3 fatty acid
  - Dietary sources: fish oil, flaxseed, walnuts
  - Beneficial effects on cholesterol, lipid metabolism, and cardiovascular health

n3/EPA and Muscle

Whitehouse et al. 2001
Omega-3 and Cancer

Proportion of tumor bearing rats

Vanamala et al., Carcinogenesis, 2008

Vitamin D

Sources
UVB radiation
Food
Seafood, mushrooms, egg yolk, fortified foods

Nomenclature
Vitamin D$_2$ (ergocalciferol)
Vitamin D$_3$ (cholecalciferol)
25-OH vitamin D
1,25(OH)$_2$ vitamin D

Vitamin D Intake Guidelines
RDA (1997 IOM)
19-50 y: 200 IU/d
50-70 y: 400 IU/d

The 2005 Dietary Guidelines for Americans recommendation advised older adults, people with dark skin, and people exposed to insufficient sunlight to consume 1000 IU/d.

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Contributing Factors to Vitamin D Status
Age
Ethnicity
Salt-sensitive hypertension
Increased protein excretion in salt-sensitive individuals and Dahl rats with salt loading
Adiposity/obesity
Vitamin D is associated with:
- Calcium metabolism
- Fracture Risk/BMD

Smith et al., J Nutr, 2005

Vitamin D and PTH

Erkal, Osteo Int, 2006

Smith et al., J Nutr, 2006

Vitamin D and Disease

Vitamin D status has been related to:
- Fractures, fracture risk, BMD
- Muscle strength/function, falls
- Cancer (prostate, breast, colon)
- Multiple sclerosis
- Blood pressure/heart disease
- Diabetes (type 1)

Bischoff-Ferrari, Am J Clin Nutr, 2006

Recommendations

Encourage adequate vitamin D:
- Intake
  - Fortified milk, orange juice
  - Fish (salmon, tilapia, tuna)
  - Few other sources...
- Sunlight
- Supplements

...the criterion for broad-based supplementation in the general population is not fulfilled, except for in high risk groups, such as the elderly...all other persons with negligible exposure to sunshine.

Space Food

<table>
<thead>
<tr>
<th>Flight Requirement (per day)</th>
<th>VD D (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>572 ± 45</td>
</tr>
<tr>
<td>Salmon</td>
<td>236</td>
</tr>
<tr>
<td>Tuna</td>
<td>152</td>
</tr>
<tr>
<td>Breakfast Drink</td>
<td>116</td>
</tr>
<tr>
<td>Tuna Noodle Casserole</td>
<td>116</td>
</tr>
<tr>
<td>Cornflakes</td>
<td>64</td>
</tr>
<tr>
<td>Tuna Salad Spread</td>
<td>64</td>
</tr>
<tr>
<td>Bran Chex</td>
<td>68</td>
</tr>
<tr>
<td>Scrambled Eggs</td>
<td>64</td>
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<tr>
<td>Bread Pudding</td>
<td>64</td>
</tr>
<tr>
<td>Granola w/Raisins</td>
<td>44</td>
</tr>
<tr>
<td>Tapioca Pudding</td>
<td>44</td>
</tr>
<tr>
<td>Teriyaki Sauce</td>
<td>36</td>
</tr>
<tr>
<td>Pork Chips</td>
<td>32</td>
</tr>
<tr>
<td>Vegetable Quiche</td>
<td>28</td>
</tr>
<tr>
<td>Pudding Soup</td>
<td>28</td>
</tr>
</tbody>
</table>
Upper Limits

2000 IU/day is current defined IOM no observed adverse events limit (NOAEL)
Studies of higher levels have proven safe...

Sunlight does not result in toxicity
Watch multivitamins (vit A and other nutrients may be in excess)

Vitamin D Toxicity

Hypercalcemia, hypercalciuria, soft tissue calcification, kidney stones

Vitamin D

Vitamin D status goes down after long-duration spaceflight.

Questions:
Is the stability of vitamin D in the food system and supplement different during spaceflight?
Is the daily dose not high enough to maintain status?
Does vitamin D metabolism change during spaceflight?

Stability Study

Stability of vitamin D in food/supplement is not altered during spaceflight

Question:
Is the daily dose simply not high enough to maintain status in an environment with no sun exposure?
Polar Vitamin D

3 levels of vitamin D supplementation:
- 400 IU/d (n = 18)
- 1000 IU/d (n = 19)
- 2000 IU/d (n = 18)

3 blood collections and diet logs
- 25D, 1,25D, PTH, Ca, VDBP, NTX

Double blinded supplementation

Compliance
84% on average

Vitamin D status is related to body weight…
- what if we exclude subjects with BMI >29 kg/m²?

Could compliance be improved with a weekly dose instead of a daily dose?
Is vitamin D status related to observed changes in immune function during polar winters?
Residual Questions…

Is a higher, less frequent dose as effective as a daily or weekly dose? Does a high dose result in a high serum concentration of 25-OH vitamin D (or metabolites) or alter serum or urine calcium?

Vitamin D Dosing Study

2,000 IU/d
10,000 IU/wk
50,000 IU weekly x4; then 1/mo
Vit D (and metabolites)
Ca, etc.
Dist, ur
1 subject in 2000 IU/d group had 2 values >150 nmol/L.
2 subjects in 50000 IU group had 3-5 values > 150 nmol/L.

Nutrition SMO

Calcium
Collagen Crosslinks

Bone Resorption

Space Flight:
- Urinary collagen xlinks
- Urinary Ca
- Urinary OH-Proline
- N-Telopeptide

Bone resorption is increased during flight

Bone Formation/Resorption

Calcium Isotopes

Calcium Isotopes

Higher $\delta^{44}$Ca = “heavier”
Lower $\delta^{44}$Ca = “lighter”
URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly

Distillation Assembly

Urine Calcium

![Graph showing urine calcium levels before and during flight with a 24% increase.]

Urine Volume

![Graph showing urine volume before and during flight with a 17% decrease.]

Pre-flight

In-flight

1200

2000

3000

4000

mL / d

24 h Urine Vol (mL)

Regenerative ECLSS

![Diagram of a regenerative life support system.]

450

600

Urine Calcium

Preflight

Inflight

0

Urine Volume

0

1000

2000

3000

4000

mL / d

24 h Urine Vol (mL)

-17%
Current folate intakes do not maintain folate status
How much folate is in the food? If enough – then:
Is folate stable on orbit? If it is – then:
What is changing?

Nutrient Stability

Nutrient Stability

Radiation

Vitamin E
Excess sodium intake (and related effects on acid/base physiology) is associated with a number of health issues:

- Bone loss
- Increased renal stone risk
- Impaired muscle performance/protein catabolism
- Altered glucose metabolism
- Altered vitamin D metabolism
- Hypertension

With the exception of hypertension, all of these other factors have been raised as concerns for space travelers.

The space food system is very high in sodium. In 2005-2006, the average US intake of Na was estimated at 3,436 mg Na/d* In 1990-1999, the average US intake of Na was estimated at:

- 3,377 mg for 31-50 yo M**
- 3,539 mg for 31-50 yo F

High sodium has been shown in bed rest (and ambulatory) studies to exacerbate bone breakdown (Heer, et al.)

** http://www.cdc.gov/media/pressrel/2009/r090326.htm

The excess sodium is bound to glycosaminoglycans in skin, exchanging with a hydrogen ion.

** IOM, Dietary Reference Intakes, 2004

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Acidosis

Acid/Base and Bone

Excess dietary sodium

CO$_3^{2-}$ Ca$^{2+}$ exchange in skin GAGs

Na$^+$/H$^+$ exchange

Na$^+$ GAG$^-$ Na$^+$

CO$_3^{2-}$ Ca$^{2+}$ GAG$^-$

Iron (RBCs, and oxidative damage)

Iron and Oxygen

Radiation/oxygen issues have implications for cataracts and other health issues.

Total Body Iron

Mission Duration (days)

Mir ISS NEEMO 5

0 50 100 150 200

Days of flight

8(OH)dG (% $\Delta$ from Preflight)

0 200 400 600 800

Mission Duration (days)

Iron and Oxygen

Mission Duration (days)

Mir ISS NEEMO 5

0 50 100 150 200

Days of flight

8(OH)dG (% $\Delta$ from Preflight)

0 200 400 600 800

Mission Duration (days)
Iron and Oxidative Damage

Bed Rest

NEEMO

Supplements

Outliers

EVA Pilot Study

Zwart et al., J Nutr, 2009

Zwart et al., Aviat Space Environ Med, 2009

Zwart et al., J Appl Physiol, 2004

18
Bone Resorption

Week of Bed Rest

% from baseline

Pre Measurement
FD15
FD30
FD60
FD12
FD18
R+0
R+30

NTX (% change)

Nutrition
Exercise
Pharmacology
Gravity

Potential Countermeasures

Exercise Countermeasures

Artificial Gravity

Smith et al., J Appl Physiol, 2009
Shackelford et al., JAP, 2004
Smith et al., Bone, 2008

Bone Resorption
Bone Formation

Bisphosphonates

Nutrition and Bone

Vitamin K

Nutrition and Bone

Animal vs. Vegetable

Dietary Protein

Animal protein

Diets rich in animal protein tend to have greater overall acid potential

Renal net acid excretion

Vegetables/fruits

Also contain substantial amounts of base precursors (and K)

APro/K provides an estimation of acid/alkali load

Dietary protein increases urinary calcium

Oxidation of excess protein yields acid (H+, H₂SO₄)

Renal buffering

Bone: reservoir of base

Osteoclasts are more active at lower pH

Excess protein: beneficial or harmful to bone?

Many factors influence the net effect
**Pro K**

- Controlled dietary intake
- High or Low APro:K
- Monitored dietary intake

**Blood/Urine markers**

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**EXAMPLE Menu**

**High APro/K Day 1 Example**

- Oatmeal w/ Brown Sugar Hot and Sour Soup
- Seasoned Scrambled Eggs
- Grilled Pork Chop
- Smoked Turkey
- Bread Pudding
- Granola Bar
- Cheese
- Grits
- Pasta w/Pesto Sauce
- Butter Cookies
- Fruit Cocktail
- Green Beans & Mushrooms
- Broccoli au Gratin
- Almonds
- Apple Cider
- Cashews
- Pineapple Drink
- Tea
- Brownies
- Banana Pudding
- Tropical Punch
- Orange-Grapefruit Drink
- Oatmeal w/ Raisins & Spice
- Vegetarian Vegetable Soup
- Chicken Noodle Soup
- Waffles
- Grilled Cheese
- Tuna Peanut Butter
- Almonds
- Cheese Tortellini
- Curry Sauce w/ Vegetables
- Tortillas
- Cocoa
- Carrot Coins
- Creamed Spinach
- Macadamia Nuts
- Orange Juice
- Tofu w/ Hot Mustard Sauce
- Apples w/ Spice
- Water (250 mL)
- Tea
- Potato Medley
- Candy Coated Almonds
- Candied Yams
- Water (250 mL)
- Japanese Tomato Jelly Drink
- Drink

**Low APro/K Day 1 Example**

- Oatmeal w/ Brown Sugar
- Lentil Soup
- Shrimp cocktail
- Chicken Noodle Soup
- Grilled Cheese
- Tuna Peanut Butter
- Almonds
- Cheese Tortellini
- Curry Sauce w/ Vegetables
- Tortillas
- Cocoa
- Carrot Coins
- Creamed Spinach
- Macadamia Nuts
- Orange Juice
- Tofu w/ Hot Mustard Sauce
- Apples w/ Spice
- Water (250 mL)
- Tea
- Potato Medley
- Candy Coated Almonds
- Candied Yams
- Water (250 mL)
- Japanese Tomato Jelly Drink
- Drink
Acid/Base and Bone

High protein, low potassium diet

Acid Load >> Alkali Load

\[
\text{H}^+ >> \text{Organic anions}
\]

\[
\text{Na}^+/\text{H}^+ \text{ exchange in skin}
\]

GAGs

\[
\text{GAG}^- \text{ GAG}^- \text{ Na}^+
\]

\[
\text{Ca}^{2+} \text{ excretion}
\]

\[
\text{H}^+ >> \text{Organic anions}
\]

Arachidonic acid
Bed rest
Hindlimb unloading
Spaceflight
Ionizing radiation/UVC

PIF
RANKL
\(\alpha\)-LPS

Inflammation

NF-kB
kB Inhibitor

NF-kB (active)

Muscle proteolysis

Bone resorption

Muscle proteolysis

Inflammation/Bone

Inflammation Markers

Pre mean
L-10
FD15
FD30
FD60
FD120
FD180
R+0
R+30

NF
\(\kappa\)
B

CXCL 5 (pg/mL)

0
2000
4000
6000
8000

3-MH (\(\mu\)mol/g creat)

Pre
Inflight
R+0
R+30

RANKL
TNF-\(\alpha\)

NTX (nmol/d)