Space Nutrition

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

**Systems**
- Bone
- Muscle
- Cardio
- Fluid/Electrolyte
- Immuno
-ology
- Hematology

**Immunology**
- Neuro
- Endo
- GI
- Gastro

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

**Vehicle/Mission**
- Quality
- Food System
- radiation
- EVA
- Schedule

---

**Energy**

- Weight (kg)
  - Hypocaloric Ambulatory
  - Hypocaloric Bedrest
  - Normocaloric Ambulatory
  - Normocaloric Bedrest

**Energy and Cardio/Ox. Damage**

- IH and Loucks, 2004
- Biolo, 2007
- Heer et al., 2007
- Smith et al., J Nutr, 2005

**Energy and Muscle/Bone**

- Leucine oxidation (μmol/kg LBM/min)

---

---

https://ntrs.nasa.gov/search.jsp?R=20100011381 2020-04-18T10:52:47+00:00Z
Protein (and muscle)
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.

Inflammation

Bed rest
Hindlimb unloading
Spaceflight
Ionizing radiation/UVC

PIF
Arachidonic acid
NF-κB
LPS
RANKL
TNF-α

NF-κB (active)

Inflammatory Markers

...procatabolic hormonal and cytokine environment...
**Inflammation/Muscle**

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.*

**Protein/Muscle**

Hyper-catabolic conditions associated with proteolysis:
- Cancer cachexia
- Cachexia associated with heart failure
- Sepsis
- Starvation
- Metabolic acidosis
- Stress/trauma associated with excess glucocorticoids
- Space flight

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 (Vitkin 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, Bodai et al. 2000)
- Space flight (Kerns et al. 2001, Rikay 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.

**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
- Muscle strength/function
- Cancer (prostate, breast, colon)
- Multiple sclerosis
- Diabetes
- Parkinson's Disease
- Tuberculosis
- Incidence of C-section
- The common cold

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)

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>Meal</th>
<th>Vitamin D (IU)</th>
<th>Flight Requirement (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast Drink</td>
<td>116</td>
<td>450</td>
</tr>
<tr>
<td>Salmon</td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>Tuna</td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>Tuna Noodle Casserole</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Cornflakes</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Tuna Salad Spread</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Bran Chex</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Scrambled Eggs</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Bread Pudding</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Granola w/Raisins</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Tapioca Pudding</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Teriyaki Beef</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Pork Chops</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Vegetable Quiche</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Potato Soup</td>
<td>28</td>
<td></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

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?
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

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

1000 or 2000 IU/d was enough to reach 80 nmol/L and maintain vitamin D status

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?
In addition to BMI, the efficacy of vitamin D supplementation is affected by baseline status.

Compliance:
- 2000 IU/d: 91%
- 10,000 IU/wk: 97%

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?
1 subject in 2000 IU/d group had 2 values > 150 nmol/L.
2 subjects in 50,000 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

Bone resorption is increased during flight

Smith et al., JCEM, 1998

Bone Formation/Resorption

Calcium Isotopes

\[ \delta^{44} \text{Ca} = \left( \frac{^{44}\text{Ca}}{^{40}\text{Ca}} \right)_{\text{Sample}} / \left( \frac{^{44}\text{Ca}}{^{40}\text{Ca}} \right)_{\text{Standard}} - 1 \] \times 1000

Higher \( \delta^{44} \text{Ca} \) = “heavier”
Lower \( \delta^{44} \text{Ca} \) = “lighter”

Skulan et al., Clin Chem, 2007
Regenerative ECLSS

URINE PROCESSOR ASSEMBLY

Urine Calcium

Urine Volume

Recycle Filter Tank Assembly

Distillation Assembly

UPA
Urine Calcium

Preflight

Inflight

0

10

20

30

40

mg/dL

+49%

Nutrition SMO

URINE PROCESSOR ASSEMBLY

Recycle Filter
Tank Assembly

Distillation Assembly

Preflight

Inflight
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?

Folate

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. Russell, Canadian, French, German, and Japanese sodium contents are shown. The ISS requirement is 3500 mg/d. 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 and 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.). The excess sodium is bound to glycosaminoglycans in skin, exchanging with a hydrogen ion.
Acidosis

From Dr. L Frassetto (UCSF) 10/6/09 JSC presentation

Acid/Base and Bone

Excess dietary sodium

Iron (RBCs, and oxidative damage)

Iron and Oxygen

Total Body Iron

Iron and Oxygen issues have implications for cataracts and other health issues.

Radiation/oxygen issues have implications for health issues.
Bone Resorption

Week of Bed Rest

% from baseline

Pre Measure

FD15
FD30
FD60
FD12
FD0
FD18
R+0
R+30

NTX (% change)

Smith et al., J Appl Physiol, 2009

Nutrition
Exercise
Pharmacology
Gravity

Exercise Countermeasures

Exercise within LBNP

Smith et al., JBMR, 2003
Shackelford et al., JAP, 2004
Smith et al., Bone 2008

Potential Countermeasures

Nutrition
Exercise
Pharmacology
Gravity

Artificial Gravity

CON
 AG

Smith et al., JAP, 2009
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

Dawson-Hughes et al. 2002
**APro:K and Bone**

Controlled dietary intake
- High or Low APro:K
- Monitored dietary intake
- Blood/Urine markers

**Pro K**

Example Menu

High APro/K Day 1 Example

- Whole Wheat Brown Rice
- Country Ham and Cheese Soup
- Broccoli & Cheese Casserole
- Mixed Greens with Cherry Tomatoes, Red Onion, and Dijon Vinaigrette
- Chocolate Ice Cream

Low APro/K Day 1 Example

- Whole Wheat Brown Rice
- Country Ham and Cheese Soup
- Broccoli & Cheese Casserole
- Mixed Greens with Cherry Tomatoes, Red Onion, and Dijon Vinaigrette
- Chocolate Ice Cream

**EVA Pilot Study**

**Design**

**EXAMPLE Menu**

**Pro K**

**Nutrition and Bone**
Acid/Base and Bone

High protein, low potassium diet

Acid Load >> Alkali Load

H⁺ >> Organic anions

Na⁺/H⁺ exchange in skin GAGs

Excess dietary sodium

Arachidonic acid
Bed rest
Hindlimb unloading
Spaceflight
Ionizing radiation/UVC

PIF
RANKL
TNF-α
α-LPS

Inflammation

NF-κB
kB Inhibitor
kB Inhibitor
NF-κB
NF-κB (active)
NF-κB (active)
NF-κB (active)
NF-κB (active)
NF-κB (active)

Inflammatory Markers

Inflammation/Bone

Muscle proteolysis
Bone resorption

CXCL 5 (pg/mL)

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

2000
4000
6000
8000

Pre
Inflight
R+0
R+30

1000
1500

TNFa (pg/mL)

3-MH (μmol/g creat)