**Space Nutrition**

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

**Systems**
- Bone
- Muscle
- Cardio
- Fluid/Electrolyte
- Immuno
- Hematol
- Neuro
- Endo
- GI
- BHP

**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**
Protein (and muscle)
Muscle Protein

Protein Synthesis Breakdown

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

NF-κB

...procatabolic hormonal and cytokine environment...

Inflammatory Markers

Pre mean

Pre mean

NF-kB (active)

NF-kB inhibitor

kB Inhibitor

Ub-prot activation

Muscle proteolysis

Protein synthesis vs. breakdown

Exercise

Catabolic effectors (e.g., stress/cortisol, hypocaloric diet, T3)

Intake (and/or supplement) of control group

Amino acid supplementation

Muscle Protein

Protein Synthesis

Protein Breakdown

Amino Acids

FD 15

FD 20

FD 25

FD 30

FD 35

FD 40

FD 50

FD 55

FD 60

FD 70

FD 80

FD 90

FD 95

FD 100

FD 11

FD 115

FD 120

FD 130

FD 135

FD 140

FD 145

FD 150

FD 160

FD 17

FD 175

FD 185

Protein Intake (gm/kg Body Weight/day)

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.


[Pierson et al., 2009]
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-catabolic conditions associated with upregulation of the ubiquitin-proteasome system:
- Cancer cachexia (Lurie et al. 2001; Tisdale et al. 2009)
- 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, Boli 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
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 D₃ (ergocalciferol)
Vitamin D₃ (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.

Vitamin D Status
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, 2006
Smith et al., J Nutr, 2005

Vitamin D is associated with:
- Calcium metabolism
- Fracture Risk/BMD
- Muscle strength/function
- Cancer
- Cardiovascular health
- Immune function
- Diabetes
- Multiple Sclerosis
- Dementia
- Parkinson’s Disease
- Tuberculosis
- Incidence of C-section
- The common cold

25 (OH) Vitamin D (nmol/L)

Cardiovascular health
Immune function
Diabetes
Multiple Sclerosis
Dementia
Parkinson’s Disease
Tuberculosis
Incidence of C-section

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)

Vitamin D and PTH

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.
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

Compliance
84% on average

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

Residual Questions...
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%
- 10000 IU/wk: 97%

Polar I (2000 IU/d)

Polar II

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 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

Bone resorption is increased during flight

Smith et al., JCEM, 1998

Bone Formation/Resorption

Calcium Isotopes

40Ca 42Ca 43Ca 44Ca 46Ca 48Ca
97% 0.65% 0.11% 2.09% 0.004% 0.19%

Higher δ44Ca = "heavier"
Lower δ44Ca = "lighter"

40Ca   42Ca    43Ca     44Ca     46Ca      48Ca
97%    0.65%   0.11%   2.09%   0.004%   0.19%

Skulan et al., Clin Chem, 2007

Calcium Isotopes
URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly
Distillation Assembly

URINE CALCIUM

Preflight Inflight

+24%

Urine Volume

-17%
Urine Calcium

Preflight

Inflight

mg/dL

+49%

Recycle Filter

Tank Assembly

URINE PROCESSOR ASSEMBLY

Nutrition SMO

BLOOD (Ted SERUM)
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?
Vitamin K

Fluid Intake

Fluid Shift

Renal Stone Risk

Nutrition SMO

UMS
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

**IOM, Dietary Reference Intakes, 2004

In 2005-2006, the average US intake of Na was estimated at 3,436 mg Na/d.*

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

Excess sodium intake leads to non-osmotic (i.e., non-fluid retaining) storage of sodium in skin, exchanging with a hydrogen ion.

Mechanism

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

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

Acid/Base and Bone

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

Iron (RBCs, and oxidative damage)

Iron and Oxygen

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

Total Body Iron
Bone Resorption

Week of Bed Rest

% from baseline

Pre Measure

FD15

FD30

FD60

FD120

FD180

R+0

R+30

NTX (% change)

Smith et al., J Appl Physiol, 2009

Pos

-20

-10

0

10

20

30

40

50

60

70

80

90

100

110

Smith et al., JBMR, 2003

Shackelford et al., JAP, 2004

Smith et al., Bone 2008

CON

AG

Nutrition

Exercise

Pharmacology

Gravity

Artificial Gravity.1

Exercise Countermeasures

Potential Countermeasures
Dietary protein increases urinary calcium
Oxidation of excess protein yields acid (H⁺, \( H_2SO_4 \))
- 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

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
**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

<table>
<thead>
<tr>
<th>Breakfast/Bar &amp; Spun</th>
<th>Unit and Snack Snack</th>
<th>Snack &amp; Bar Snack</th>
<th>Snack &amp; Bar Snack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oatmeal w/ Brown Sugar</td>
<td>Oatmeal w/ Brown Sugar</td>
<td>Oatmeal w/ Brown Sugar</td>
<td>Oatmeal w/ Brown Sugar</td>
</tr>
<tr>
<td>Granola Bar Cheese</td>
<td>Granola Bar Cheese</td>
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<td>Granola Bar Cheese</td>
</tr>
<tr>
<td>Fruit Cocktail</td>
<td>Fruit Cocktail</td>
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<td>Fruit Cocktail</td>
</tr>
<tr>
<td><strong>Pro K</strong></td>
<td><strong>Pro K</strong></td>
<td><strong>Pro K</strong></td>
<td><strong>Pro K</strong></td>
</tr>
<tr>
<td>Apple Cider Cashews</td>
<td>Apple Cider Cashews</td>
<td>Apple Cider Cashews</td>
<td>Apple Cider Cashews</td>
</tr>
<tr>
<td>Tea</td>
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| **High APro/K Day 1 Example**

### Low APro/K Day 1 Example

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| **Low APro/K Day 1 Example**

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**Nutrition and Bone**

**EVA Pilot Study**

**Design**

**Postflight**

**Preflight**

**Inflight**

**FD15**

**FD60**

**FD120**

**FD180**

**R+30**

**R+180**

**R+365**

NOTE: the low ratio diet is **NOT** low protein, and **NOT** vegetarian.  
NOTE: the pattern above (red or blue) is an example, your pattern may vary.

Blood/Urine (24-h F; 48-h G) will be collected at the end of each session, and on L-10 and R+6.
Muscle, cancer...

Vanamala et al., Carcinogenesis, 2008

Omega-3 Fatty Acids (EPA)

Proportion of tumor bearing rats

Omega-3 (EPA) and Bone

Muscle, bone, and cancer...

Omega-3 (EPA) and Bone

Muscle, bone, and cancer...

Nutrient Requirements

Energy
CHO (fiber), Fat, Protein
Fat-Soluble vitamins
Water-sol vitamins
Minerals
Fluid

Systems

Bone
Muscle
Cardio
Fluid/Electrolyte
Immunology
Hematology
Neuro, Ethos
GI, BHP

Earth

Physiology
Medicine
Technology
Education

Countermeasures

Energy
Amino acids
Protein
Sodium
Fatty acids
Antioxidants
Other

Bisphosphonates
KClorate
Medications
Exercise
Other

Vehicle/Mission

Food System
Duration
Radiation
EVA
Schedule

Zwart, et al. 2010