Space Nutrition

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

**Systems**
- Bone
- Muscle
- Cardio
- Fluid
- Electrolyte
- Immunology
- Hematology
- Neuro
- Endo
- GI
- BHP

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

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

**Energy**

**Energy and Cardio/Ox. Damage**

**Energy and Muscle/Bone**

**Energy**

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

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...
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.

Hypercatabolism

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

Hypercatabolism

Hyper-catabolic conditions associated with upregulation of the ubiquitin-proteasome system:
- Cancer cachexia (Lute et al. 2001; Tisdale et al. 2009)
- Cachexia associated with heart failure (Flippatos et al. 2005, Freman et al. 1998)
- Sepsis (Vivas 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, Bokil et al. 2000)
- Space flight (Iemato 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.

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

Other metabolites:
- 24,25(OH)$_2$D$_3$
- 25,26(OH)$_2$D$_3$
- 35 others...
Vitamin D is associated with:
- Calcium metabolism
- Fracture Risk/BMD

Smith et al., J Nutr, 2006
Smith et al., J Nutr, 2005

SN
Control
Pre flight
Post flight

25 (OH) Vitamin D (nmol/L)

0 10 20 30 40 50 60 70 80 90 100

Vitamin D is associated with:
- Calcium metabolism
- Fracture Risk/BMD
- Muscle strength/function
- Cancer (prostate, breast, colon)
- Multiple sclerosis
- Dementia
- Parkinson's Disease
- Tuberculosis
- Incidence of C-section
- The common cold

Smith et al., J Nutr, 2006
Smith et al., J Nutr, 2005

SN
Control
Pre flight
Post flight

25 (OH) Vitamin D (nmol/L)

0 10 20 30 40 50 60 70 80 90 100

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.
Upper Limits

2000 IU/day is current defined IOM no observed adverse events limit (NOAEL)

Studies of higher levels have proven safe...

Vitamin D Toxicity

Hypercalcemia, hypercalciuria, soft tissue calcification, kidney stones

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%

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

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 Formation/Resorption

Bone Resorption

Calcium Isotopes

Calcium Isotopes

Higher δ⁴⁴Ca = “heavier”
Lower δ⁴⁴Ca = “lighter”

N-Telopeptide

Space Flight:
↑ Urinary collagen xlinks
↑ Urinary Ca
↑ Urinary OH-Proline
↑ VCa

Bone resorption is increased during flight

Smith et al., JCEM, 1998

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

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

Skulan et al., Clin Chem, 2007
Regenerative ECLSS

URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly

URINE PROCESSOR

Distillation Assembly

UPA

Urine Calcium

Urine Volume

Regenerative ECLSS

Recycle Filter Tank Assembly

Distillation Assembly

UPA

Urine Calcium

Urine Volume
Urine Calcium

Nutrition SMO

URINE PROCESSOR ASSEMBLY
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?

Radiation

Vitamin E

Nutrient Stability

Tortillas
Almonds
Salmon
Broccoli au Gratin
Dried apricots
Vitamin D supps
Multivitamin supps

Amino Acids
Fatty acids

Thiamin
Niacin
Riboflavin
Folate
Biotin
Pantothenate
Vitamin A (βcarotene)
Vitamin D
Vitamin E
Vitamin K

Zwart et al., J. Food Sci., 2009
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.

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


\* http://www.cdc.gov/media/pressrel/2009/r090326.htm
\** IOM, Dietary Reference Intakes, 2004
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

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

Total Body Iron

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<thead>
<tr>
<th>Mission Duration (days)</th>
<th>Iron intake</th>
<th>Red Blood Cell Mass (mL/kg body weight)</th>
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<th>Pre Mean</th>
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<th>FD60</th>
<th>FD180</th>
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Bone Resorption

Week of Bed Rest

% from baseline

Pre Measure
FD15
FD30
FD60
FD120
FD180
R+0
R+30
R+60
R+90
R+120
R+150
R+180
R+210
R+240

NTX (% change)

Smith et al., J Appl Physiol, 2009

Shackelford et al., JAP, 2004

Smith et al., Bone, 2008

Con
AG

Exercise Countermeasures

Nutrition
Exercise
Pharmacology
Gravity

Bone Resorption

Smith et al., J Appl Physiol, 2009

Artificial Gravity.1

Exercise within LBNP

Smith et al., JAP, 2004

Smith et al., Bone, 2008
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

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
APRO:K and Bone

Controlled dietary intake
High or Low APRO:K
Monitored dietary intake

Blood/Urine markers

Pro K

Preflight
L-180  L-45  FD15  FD30  FD60  FD120  FD180  FD360
Apro K Apro K Apro K Apro K Apro K Apro K Apro K Apro K

Inflight
Postflight
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+5.

EXAMPLE Menu

High APRO:K Day 1 Example
- Oatmeal w/ Brown Sugar
- Seasoned Scrambled Eggs
- Grilled Pork Chop
- 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

High APRO:K Day 1 Example
- Oatmeal w/ Raisins & Spice
- Vegetarian Vegetable Soup
- Chicken Noodle Soup
- Waffles
- Grilled Chicken
- 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

Low APRO:K Day 1 Example
- Oatmeal w/ Brown Sugar
- Vegetable Soup
- Chicken Noodle Soup
- Waffles
- Grilled Chicken
- 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)

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- Tofu w/ Hot Mustard Sauce
- Apples w/ Spice
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- Tea
- Potato Medley
- Candy Coated Almonds
- Candied Yams
- Water (250 mL)

Supplement
Grape juice
Vitamin E
NAC

Nutrition and Bone

Pro K
Acid/Base and Bone

High protein, low potassium diet

**Acid Load >> Alkali Load**

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

**Na+/H+ exchange**

\[ \text{GAG}^- \text{ >> GAG}^- \text{ Na}^+ \text{ CO}_3^{2-} \text{ Ca}^{2+} \]

**Excess dietary sodium**

Arachidonic acid

Bed rest

Hindlimb unloading

Spaceflight

Ionizing radiation/UVC

PIF

RANKL

TNF-\(\alpha\)

\(\alpha\) LPS

Inflammation

**NF-kB**

kB Inhibitor

NF-kB (active)

Muscle proteolysis

Inflammation/Bone

**NF-kB**

kB Inhibitor

NF-kB (active)

Muscle proteolysis

**Bone resorption**

Inflammatory Markers

**Inflammation**

Bed rest

Hindlimb unloading

Spaceflight

Ionizing radiation/UVC

PIF

LPS

RANKL

TNF-\(\alpha\)

Inflammatory Markers

**NF-kB**

kB Inhibitor

NF-kB (active)

Muscle proteolysis

**Bone resorption**

Inflammatory Markers

**NF-kB**

kB Inhibitor

NF-kB (active)

Muscle proteolysis

**Bone resorption**

**NF-kB**

kB Inhibitor

NF-kB (active)

Muscle proteolysis

**Bone resorption**