Space Nutrition

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

**Systems**
- Muscle
- Cardio
- Fluid/Electrolyte
- Immunology
- Hematology
- Neuro
- GI
- MSMP

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

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

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**Energy**

- [Graph showing energy intake over mission duration]

**Energy and Cardio/Ox. Damage**

- [Graphs showing energy intake and cardiovascular damage]

**Energy and Muscle/Bone**

- [Graphs showing muscle and bone changes]

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**References**

- Florian, 2004
- W. Carpentier
- Stein, 2002
- Ihle and Loucks, 2004
- Biolo, 2007
- Heer et al., 2005
- Smith et al., J Nutr, 2005
Nutrition SMO

Protein (and muscle)

Amino Acids

Dietary Protein
Unloading-induced atrophy is a relatively uncomplicated form of muscle loss, and 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.

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

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 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.

Vitamin D: Review

Holick, AJCN, 2004

Other metabolites:
- 24,25(OH)$_{2}$D$_{3}$
- 25,26(OH)$_{2}$D$_{3}$
- 35 others...

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

SN
Control
Pre flight
Post flight

25 (OH) Vitamin D (nmol/L)

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

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 currently 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 simply 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

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.

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
- \( V_v \)

Bone resorption is increased during flight

Bone Formation/Resorption

Calcium Isotopes

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

\[ \delta^{44}\text{Ca} = \left( \frac{^{44}\text{Ca}}{^{46}\text{Ca}} \right)_{\text{sample}} - 1 \times 1000 \]

Skulan et al., Clin Chem, 2007

Smith et al., JCEM, 1998
Regenerative ECLSS

URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly
Distillation Assembly

UPA

Urine Calcium

Urine Volume

Preflight: 0, 150, 300 mg/day
Inflight: 450, 600 mg/day

Preflight: 0, 1000 mL/d
Inflight: 1000, 2000 mL/d

-17%
Urine Calcium

Recycle Filter
Tank Assembly
Distillation Assembly

Nutrition SMO

URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly

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?

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

Vitamin B6
Vitamin B12

Folate
Biotin
Pantothenate
Vit A (β-carotene)
Vitamin D
Vitamin E
Vitamin K

0.05
0.06
0.07
0.08
0.09
0.10

0.11

0.2

-60
-40
-20
0
20
40

-100
-50
0
50
100
150

α-tocopherol (% change)

γ-tocopherol (% change)

Radiation

Vitamin E
**Vitamin K**

- Graph showing Vitamin K intake over different days.
- Bar chart representing the intake of Vitamin K.

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**Fluid Intake**

- Graph showing fluid intake over a period.
- Data points indicating fluid intake levels.

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**Fluid Shift**

- Graphs showing changes in Total Body Water, ECF, and Plasma Volumes.
- Data points illustrating fluid shift.

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**Renal Stone Risk**

- Graphs indicating renal stone risk.
- Data points showing risk levels.

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**Nutrition SMO**

- Image of a person engaging in nutrition activities.
- Chart showing nutrient intake.

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**UMS**

- Diagram of the UMS system.
- Components labeled: ISS UMS, AVIONICS MODULE, MAIN POWER & AM/MM INTERFACE CONNECTOR, RS-232 CONNECTOR, SSC OPS WIRELESS ETHERNET ANTENNA.
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, with the exception of hypertension, all of these other factors have been raised as concerns for space travelers.

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

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

Recap 3

1. The higher the acid load, the higher you are.
2. The more you drink fluids, the higher the body is in alkali.
3. The lower the acid load, the more you drink fluids.
4. The more you drink fluids, the higher the body is in alkali.
5. The higher the acid load, the higher the body is in alkali.
6. The more you drink fluids, the higher the body is in alkali.
7. The higher the acid load, the higher the body is in alkali.
8. The more you drink fluids, the higher the body is in alkali.
9. The higher the acid load, the higher the body is in alkali.
10. The more you drink fluids, the higher the body is in alkali.

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
Iron and Oxidative Damage

Bed Rest

NEEMO

Supplements

Outliers

EVA Pilot Study

Zwart et al., Aviat Space Environ Med, 2009

Zwart et al., J Nutr, 2009

Supplements

Grape juice
Vitamin E
NAC
**Bone Formation**

![Graph showing bone formation over time with control and exercise groups.]

**Bisphosphonates**

![Graph comparing bisphosphonate effects with control groups.]

**Nutrition and Bone**

![Images of food and nutrition facts.]

**Nutrition and Bone**

![Graph comparing dietary protein intake and bone health.]

**Vitamin K**

![Graph showing vitamin K levels and effects.]

**Dietary Protein**

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 vs. Vegetable**

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

EXAMPLE Menu

High APro/K Day 1 Example

Low APro/K Day 1 Example

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+0.
Acid/Base and Bone

High protein, low potassium diet

Acid Load >> Alkali Load

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

Na⁺/H⁺ exchange in skin GAGs

Excess dietary sodium

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

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

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

Inflammation

Bed rest
Hindlimb unloading
Spaceflight
Ionizing radiation/UVC

Arachidonic acid
LPS
PIF
TNF-\(\alpha\)
RANKL

NF-kB
kB Inhibitor

NF-kB (active)

Muscle proteolysis

Inflammatory Markers

Inflammatory Markers

Inflammation/Bone

\[ \text{CXCL 5 (pg/mL)} \]

\[ \text{TNF-\(\alpha\) (pg/mL)} \]

\[ \text{NTX (nmol/d)} \]

\[ \text{MTX (nmol/d)} \]