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
- Endo
- GI
- Ship

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=2010011381 2019-09-08T05:57:39+00:00Z
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.

Inflammation

NF-κB

Bed rest
Hindlimb unloading
Spaceflight
Ionizing radiation/UVC
PIF
RANKL
TNF-α

NF-κB (active)

kB Inhibitor

Ub-protein activation

1 Muscle proteolysis

Inflammatory Markers

...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 upregulation of the ubiquitin-proteasome system:
- Cancer cachexia (Lourie et al. 2001; Tisdale et al. 2009)
- Cachexia associated with heart failure (Filippatos et al. 2005, Freeman et al. 2005)
- Sepsis (Vivien 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, Bodi et al. 2000)
- Space flight (Iemoto 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**

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

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 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

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>450 Vit D (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>175 ± 44</td>
</tr>
<tr>
<td>Meal</td>
<td>116</td>
</tr>
<tr>
<td>Salmon</td>
<td>396</td>
</tr>
<tr>
<td>Breakfast Drink</td>
<td>32</td>
</tr>
<tr>
<td>Tuna</td>
<td>152</td>
</tr>
<tr>
<td>Tuna Noodle Casserole</td>
<td>36</td>
</tr>
<tr>
<td>Cornflakes</td>
<td>88</td>
</tr>
<tr>
<td>Tuna Salad Spread</td>
<td>84</td>
</tr>
<tr>
<td>Bran Chex</td>
<td>68</td>
</tr>
<tr>
<td>Scrambled Eggs</td>
<td>64</td>
</tr>
<tr>
<td>Bread Pudding</td>
<td>56</td>
</tr>
<tr>
<td>Granola w/Raisins</td>
<td>44</td>
</tr>
<tr>
<td>Tapioca Pudding</td>
<td>44</td>
</tr>
<tr>
<td>Teriyaki Beef</td>
<td>36</td>
</tr>
<tr>
<td>Pork Chops</td>
<td>32</td>
</tr>
<tr>
<td>Vegetable Quiche</td>
<td>28</td>
</tr>
<tr>
<td>Potato 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...

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

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?

Compliance
- 84% on average
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?
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.

Bone Formation/Resorption

Calcium Isotopes

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

Calcium Isotopes

$\delta^{44}Ca = \left( \frac{^{44}Ca / ^{40}Ca_{\text{bed}}}{^{44}Ca / ^{40}Ca_{\text{control}}} - 1 \right) \times 1000$

Skulan et al., Clin Chem, 2007

Smith et al., JCEM, 1998
Regenerative ECLSS

URINE PROCESSOR ASSEMBLY

Recycle Filter Tank Assembly
Distillation Assembly

URA

UPA

Urine Calcium

Urine Volume

-17%
Urine Calcium

Preflight

Inflight

+49%

Urine Processor Assembly

Recycle Filter
Tank Assembly

Distillation Assembly

Preflight

Inflight

Nutrition SMO
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

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.

SOLO, etc. study on 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.

H⁺ release contributes to acid load.
Acidosis

Recap 3

1. The higher the acid load and the farther you are, the worse your arterial blood is and the higher the body is in acidosis.
2. The lower the bicarbonate, the farther you are in acidosis.
3. Acid-base changes and acid-base balance are important for health.
4. Acidosis may be caused by a decrease in bicarbonate, an increase in hydrogen ions, or both.

Pathophysiology of acidosis

Acidosis and bone

- Excess dietary sodium
- Na⁺/H⁺ exchange in skin
- GAGs
- GAG⁻
- Na⁺
- Na⁺
- H⁺
- H⁺
- CO₃²⁻
- Ca²⁺
- CO₃²⁻
- Ca²⁺
- Ca²⁺ excretion

Iron

(RBCs, and oxidative damage)

Iron and oxygen

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

Total body iron

Males

Females
Potential Countermeasures

- Nutrition
- Exercise
- Pharmacology
- Gravity

Artificial Gravity.1

Exercise Countermeasures

Bone Resorption

Smith et al., J Appl Physiol, 2009

Shackelford et al., JAP, 2004

Smith et al., Bone 2008

Smith et al., JAMA, 2003
Bone Formation

Bisphosphonates

Nutrition and Bone

Nutrition and Bone

Vitamin K

Dietary Protein

Animal vs. Vegetable

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
Pro K

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

Blood/Urine markers

EXAMPLE Menu

High APro/K Day 1 Example

Dinner

Oatmeal w/ Brown Sugar
Unit and Sole Soup
Grilled Ham & Cheese Bread
Chicken Noodles
Grilled Pork Chop
Banana Pudding

Breakfast

Granola Bar
Cheese
Grits
Pasta w/Pesto Sauce
Butter Cookies

Nutrition and Bone

Pro K