Space Nutrition

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

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

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

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

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**Energy**

![Energy graph showing data over mission duration](image)

**Energy and Muscle/Bone**

![Graph showing energy and muscle/bone changes](image)

**Energy and Cardio/Ox. Damage**

![Graph showing energy and cardio/oxidative damage](image)

**Energy Intake**

![Graph showing energy intake over days](image)

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**Countermeasures**

- Bisphosphonates
- KCl citrate
- Medications
- Exercise
- Other

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![Energy graph showing data over mission duration](image)

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![Energy graph showing data over mission duration](image)

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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 pro-catabolic hormonal and cytokine environment. ....

Inflammation

NF-κB

NF-κB (active)

NF-κB inhibitor

Inflammatory Markers

...pro-catabolic 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.
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

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

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 is associated with:
- Calcium metabolism
- Fracture Risk/BMD
- Muscle strength/function
- Cancer
- Cardiovascular health
- Immune function
- Diabetes
- Multiple Sclerosis
- Dementia
- Parkinson’s Disease
- Pneumococcal 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 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>Food</th>
<th>Vitamin D (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight Requirement (per day) 400 IU</td>
<td></td>
</tr>
<tr>
<td>- 400 IU</td>
<td></td>
</tr>
<tr>
<td>- Salmon 396</td>
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</tr>
<tr>
<td>- Tuna 152</td>
<td></td>
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<tr>
<td>- Breakfast Drink 116</td>
<td></td>
</tr>
<tr>
<td>- Tuna Noodle Casserole 96</td>
<td></td>
</tr>
<tr>
<td>- Cornflakes 68</td>
<td></td>
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<tr>
<td>- Tuna Salad Spread 64</td>
<td></td>
</tr>
<tr>
<td>- Bran Chex 64</td>
<td></td>
</tr>
<tr>
<td>- Scrambled Eggs 64</td>
<td></td>
</tr>
<tr>
<td>- Bread Pudding 64</td>
<td></td>
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<tr>
<td>- Granola w/Raisins 44</td>
<td></td>
</tr>
<tr>
<td>- Tapioca Pudding 44</td>
<td></td>
</tr>
<tr>
<td>- Teriyaki Beef 36</td>
<td></td>
</tr>
<tr>
<td>- Pork Chops 32</td>
<td></td>
</tr>
<tr>
<td>- Vegetable Quiche 28</td>
<td></td>
</tr>
<tr>
<td>- Potato Soup 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?
Polar Vitamin D

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

Double blinded supplementation

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

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
- 2000 IU/d
- 10,000 IU/wk
- 50,000 IU weekly x4; then 1/mo
Vit D (and metabolites) Ca, etc.
Dist, ur
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

[Diagrams and graphs related to vitamin D dosing study, 25(OH) vitamin D levels, and calcium pools in the human body are shown.]
Collagen Crosslinks

Bone Resorption

Space Flight:
- Urinary collagen xlinks
- Urinary Ca
- Urinary OH-Proline
- Urinary N-Telopeptide

Bone resorption is increased during flight

Smith et al., JCEM, 1998

Bone Formation/Resorption

Calcium Isotopes

\[ \delta^{44}\text{Ca} = \left( \frac{^{44}\text{Ca}}{^{43}\text{Ca}} \right)_{\text{measured}} \times 1000 \]

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

Skulan et al., Clin Chem, 2007
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?
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:

- **Russians**: 3,436 mg Na/d*
- **US**: 3,377 mg for 31-50 yo M, 3,539 mg for 31-50 yo F

**NOTE:** only a few JAXA food items are on the standard menu at this point (and no ESA or CSA). These are included in the bonus foods per crew request (along with other non-standard foods).

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

**NOTE:** This is the basis for the ESA sponsored SOLO experiment on ISS.

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.

H⁺ release contributes to acid load.

**Mechanism**
Acidosis

Recap 3

- The higher the acid load and the higher you are, the worse your arterial blood comes and the higher the body's acidosis.
- Excess dietary sodium causes exchange in skin GAGs and excess urinary sodium.
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Iron (RBCs, and oxidative damage)

Iron and Oxygen

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

Total Body Iron

Mission Duration (days)
Bone Formation

Nutrition and Bone

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

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**Vitamin K**

**SOLO**

**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

<table>
<thead>
<tr>
<th>Item</th>
<th>Example Menu</th>
</tr>
</thead>
<tbody>
<tr>
<td>breakfast</td>
<td>Oatmeal w/ Brown Sugar Hot and Sour Soup Seasoned Scrambled Eggs Grilled Pork Chop Smoked Turkey Bread Pudding Granola Bar Cheese Grits Pasta w/Pesto Sauce Butter Cookies Fruit Cocktail Green Beans &amp; Mushrooms Broccoli au Gratin Almonds Apple Cider Cashews Peanuts Pineapple Drink Tea Brownies Banana Pudding Tropical Punch Orange-Grapefruit Drink Oatmeal w/ Raisins &amp; 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 Drink</td>
</tr>
</tbody>
</table>
Acid/Base and Bone

High protein, low potassium diet

Acid Load >> Alkali Load

H⁺ >> Organic anions

Na⁺/H⁺ exchange in skin

GAGs

Ca²⁺ excretion

Excess dietary sodium

Organic anions

Arachidonic acid

Bed rest

Hindlimb unloading

Spaceflight

Ionizing radiation/UVC

PIF

RANKL

TNF-α

αLPS

Inflammation

Inflammatory Markers

NF-kB

kB Inhibitor

kB Inhibitor

NF-kB (active)

NF-kB (active)

NF-kB (active)

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