The Role of Nutrition and Physical Activity in Aging Muscle and Physical Function

(Preventing Sacropenia: Loss of Muscle Mass)

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Number of Persons 65+ & 85+ U.S. 1900–2050

[Numbers in Millions]

[Bar chart showing the number of persons 65+ and 85+ in millions from 1900 to 2050, with a significant increase projected by 2050.]
% of Americans AGE 65 Expected to Live to 90

- 1940: 7
- 1960: 14
- 1980: 25
- 2000: 26
- 2050: 42
Number of Older Adults in U.S.

- 60+  48.6 M
- 65+  35.9 M
- 85+  4.6 M

65+

- Community  
  33.4 M (93.5%)
- Nursing Homes  
  1.5 M (4.5%)
- Assisted Living  
  1 M (2%)
The New Aging Reality

OLDER AMERICANS LIVE

• Longer
• Healthier
• More independently
• More functionally fit
• And in the community.
As a normal part of the aging process, individuals experience a loss of skeletal muscle. This loss of muscle has been well documented in individuals over the age of 50.

This loss of muscle tissue, with an associated loss of strength and mass, is referred to as sarcopenia ("sacro" = flesh, muscle; "penia" = deficiency).

Sarcopenia can begin as early as the 4th decade of life. However, by the 7th and 8th decades of life, a decrease in the maximal contractile strength on the order of 20-40% for both men and women is observed.
Changes in Muscle Muscle Mass with Aging

40% loss in muscle mass from 20-70 years of age - Rogers & Evans, 1993

6% decline in muscle mass per decade from age 30-70 - Fleg & Lakatta, 1988

1.4 – 2.5% decline in muscle mass per year after age 60 - Frontera et al., 2000
Changes in Muscle Muscle Mass with Aging

Lexell et al., 1988
Sarcopenia

- Involuntary loss of skeletal muscle mass, strength, and function.
- Enhanced by morbidity, chronic malnutrition, a sedentary lifestyle, and smoking.
- Limits Functional Capacity: Increases risk for incapacitation, falls, fractures, and a dependent lifestyle.

21 year old Female (BMI = 24.3 kg/m²)  
73 year old Female (BMI = 24.5 kg/m²)
### Prevalence (%) of Sarcopenia*

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Males (n=205)</th>
<th>Females (n=173)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;70</td>
<td>13.5</td>
<td>23.1</td>
</tr>
<tr>
<td>70 – 74</td>
<td>19.8</td>
<td>33.3</td>
</tr>
<tr>
<td>75 – 80</td>
<td>26.7</td>
<td>35.9</td>
</tr>
<tr>
<td>&gt;80</td>
<td>52.6</td>
<td>43.2</td>
</tr>
</tbody>
</table>

*New Mexico Elder Health Survey, Baumgartner et al. 1998*
Muscle Atrophy

Reduction in contractile protein content and fiber diameter by a decrease in protein synthesis and increase in protein degradation.

Can be permanent if disuse lasts ≥ one year

A few causes:
- Extended inactivity
- Aging (e.g., Sarcopenia)
- Starvation (malnutrition)
Muscle Fibers

Muscle from biopsied material (composite of 3 fiber types*)

- Typical cross-sectional area for sedentary person
  - Men: \(~4500-5000\mu m^2\)  
  - Women: \(~3500-4000\mu m^2\)

- Strength per unit muscle mass is same for men & women

- Men have bigger muscle fibers than women, regardless of fiber type

- Men and women can double fiber sizes with resistance training: Cross-sectional area for Olympic weightlifters
  - Men: \(~12,000-13,000\mu m^2\)  
  - Women: Rarely >7,000\mu m^2

- Men are stronger than women due to larger muscle mass

Brown, Marybeth  Advances in Molecular and Cell Biology 2004; 34: 195-208
Sarcopenia

Muscle Fiber Changes with Aging:

1) Decreased muscle fiber size (atrophy)

2) Decreased number of muscle fibers
Fast and Slow Twitch Muscle Fibers

**Slow-twitch fibers (type I)**
- always oxidative
- resistant to fatigue
- red fibers
- most myoglobin
- good blood supply

**Fast-twitch glycolytic fibers (type II)**
- white fibers (less myoglobin)
- poorer blood supply
- susceptible to fatigue

**Fast-twitch fatigue-resistant fibers (type IIb)**
- intermediate fibers
- oxidative
- intermediate amount of myoglobin
- pink to red in color
Histochemical Staining of Fiber Type
Force Production and Fatigue Curves of Fiber Types

(a) Force Production

- FG
- FOG
- SO

(b) Fatigue Curves

- FG
- FOG
- SO
Fiber Type Distribution of Different Muscle Groups Among Athletes

- Vastus lateralis
- Deltoid

**Graph 1:**
- X-axis: Students, Wrestlers, Kayakers, Runners, Lifters
- Y-axis: Percent of slow-twitch fibers
- Comparison between Vastus lateralis and Deltoid

**Graph 2:**
- X-axis: Pre-training, Post-training
- Y-axis: % Fiber type
- Changes in fiber type:
  - Type Ia (+13%)
  - Type I (no change)
  - Type IIb (-13%)
## Properties of Motor Units

<table>
<thead>
<tr>
<th>Muscle Fibers</th>
<th>Twitch properties</th>
<th>Metabolic properties</th>
<th>Name based on twitch and metabolic properties</th>
<th>Other nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slow</td>
<td>Oxidative</td>
<td>SO</td>
<td>ST, Type I</td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>Oxidative/glycolytic</td>
<td>FOG</td>
<td>FTA, FTA, Type IIA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glycolytic</td>
<td>FG</td>
<td>FTb, FTB, Type IIB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motor Neurons</th>
<th>Neuron type</th>
<th>Neuron size</th>
<th>Conduction velocity</th>
<th>Recruitment threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\alpha_2$</td>
<td>Small</td>
<td>Slow</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>$\alpha_1$</td>
<td>Large</td>
<td>Fast</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>$\alpha_1$</td>
<td>Large</td>
<td>Fast</td>
<td>High</td>
</tr>
</tbody>
</table>
Muscle Fiber Changes with Aging:

1) Atrophy

Men: 20-29 vs 60-65

- Type I - no change
- Type II - 25% decrease

Larsson et al., 1978

Men: 19-84

- Type I - 6% decrease
- Type II - 35% decrease

Lexell, 1991
Sarcopenia

Muscle Fiber Changes with Aging:

1) Atrophy

By age 85, Type II fiber CSA may be less than 50% of that for Type I fibers
Sarcopenia

Muscle Fiber Changes with Aging:

2) Decreased number of fibers

25% loss in men ages 19-37 to 70-73
(110,000 difference)  
Lexell et al., 1983

Muscle of 20 yr old - 70% fibers
Muscle of 80 yr old - 50% fibers
Lexell et al., 1988
Muscle Fiber Changes with Aging:

2) Decreased number of fibers

**Selective loss of Type II fibers:**

Type I fiber % increased from 40 to 55 in men ages 20-30 and 60-65

Larsson, 1982

- Loss of Type II fibers?
- Acquiring more Type I fibers?
Sarcopenia: Biological Mechanism

Appears to be decreased ability of satellite cells to propagate themselves

Satellite cells are required to fuse into skeletal muscle fibers and help in settings where repair & regeneration are required.

Aging muscle loses its ability to respond to anabolic stimuli, e.g. insulin, growth hormone, and amino acids. Catabolic stimuli may also play a role: IL-6, IL1-Ra, TNF-alpha are elevated in elderly people with severe sarcopenia.

Low protein intake may play a role: 1/3 of men aged >60 yrs eat less than RDA of 0.8 g/kg. Increased protein might help.

Decline in exercise, a potent stimulus to protein synthesis also contributes. Resistance exercise might help.
Sarcopenia is a Multi-Factorial Disorder

- Decreased levels of sex hormones (testosterone and DHEA)
- Decreased levels of growth hormone and insulin-like growth factor 1 (IGF-1)
- Increased cytokine production (i.e., IL-1, IL-6, TNF-α, etc.)
- Neuromuscular changes
- Smoking
- Physical inactivity
- Malnutrition (especially protein deficiency)

✓ As a result of this loss of muscle mass and strength, older individuals experience a decreased quality of life.

✓ Lack of physical exercise is one of the most important predictors of disability in elders.
Sarcopenia

- ↓ GH Secretion
- ↓ CNS Input (loss of motor neurons, altered motor unit activation, etc.)
- ↓ Estrogen/Androgen
- ↑ Fat Mass
- ↓ Inactivity
- ↓ Muscle Mass
- ↓ Muscle Quality?
- ↓ Metabolic Reserve
- Disability, Morbidity, Mortality
- ?↑ Proteasome Activity
- ?↑ IL-6
- ?↓ Protein Intake

Roubenoff, 2003
The weakness associated with sarcopenia has been shown to be associated with difficulty in rising from a chair and getting out of bed.

Decreases in muscle quality may also contribute to increased fracture risk in older individuals.

Also associated with a decrease in muscle mass and muscle strength is a decrease in the rate of force development in the muscles of elderly individuals.
Balance and muscle strength diminish: One Leg Stand
Basel - IDA Study (n=380)
Physiological Changes with Increasing Age

% Δ Related to Age

Age

20 40 60 80

100

90

80

70

60

50

40

30

20

10

0

% Δ Related to Age

Strength

BMR

Bone

Vital capacity

Blood volume

% fat

Body weight

DBP

20 40 60 80

130

120

110

100

90

80

70

60

50

40

30

20

10

0
Decline in $\dot{V}O_{2\text{max}}$ with Age in Different Groups of Males and Females

$\dot{V}O_{2\text{max}}$ decreases by about 9 percent per decade for both males and females.
Consequences of Sarcopenia

- Decreased resting energy expenditure
- Decreased insulin sensitivity
- Decreased muscle mass and strength
- Increased risk of physical disability
- Increased risk of falls
- Increased risk of mortality
Aging is associated with oxidative stress and subsequent local inflammation in skeletal muscle.

Oxidative stress (by way of increased free radical generation) causes oxidative modification and damage to protein, lipid, and DNA in skeletal muscle.

This invariably leads to cellular dysfunction and muscle protein degradation, as well as a decline in muscle mass and function.
The Disablement Pathway
(Nagi, 1965; Verbrugge & Jette, 1994)

Pathology

Impairment

*Power may be a more critical variable on which to focus resistance training protocols

Functional Limitation

Disability
**Muscle power at high or low velocity may be more important to certain functional tasks than muscle strength.**

### Speed at which we generate power is critical to lower intensity functional tasks

<table>
<thead>
<tr>
<th>Physical Performance</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>$R^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stair Climb (n=45)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1RM strength</td>
<td>-0.270</td>
<td>0.12</td>
<td>0.32</td>
<td>0.027</td>
</tr>
<tr>
<td>Leg Power*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% 1RM</td>
<td>-0.206</td>
<td>0.071</td>
<td>0.43</td>
<td>0.000</td>
</tr>
<tr>
<td>40% 1RM</td>
<td>-0.169</td>
<td>0.06</td>
<td>0.42</td>
<td>0.000</td>
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<tr>
<td><strong>Chair Rise (n=45)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1RM strength</td>
<td>-0.301</td>
<td>0.10</td>
<td>0.31</td>
<td>0.005</td>
</tr>
<tr>
<td>Leg Power*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% 1RM</td>
<td>-0.152</td>
<td>0.070</td>
<td>0.24</td>
<td>0.024</td>
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<tr>
<td>40% 1RM</td>
<td>-0.154</td>
<td>0.057</td>
<td>0.28</td>
<td>0.009</td>
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<tr>
<td><strong>Habitual Gait (n=45)</strong></td>
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<td></td>
<td></td>
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<tr>
<td>1RM strength</td>
<td>0.296</td>
<td>0.08</td>
<td>0.40</td>
<td>0.001</td>
</tr>
<tr>
<td>Leg Power*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% 1RM</td>
<td>0.223</td>
<td>0.049</td>
<td>0.51</td>
<td>0.000</td>
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<tr>
<td>40% 1RM</td>
<td>0.214</td>
<td>0.037</td>
<td>0.59</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*adjusted for age, body mass, and gender

Contraction velocity alone was more important to walking speed than muscle strength in older adults

<table>
<thead>
<tr>
<th>Function</th>
<th>Standardized β</th>
<th>p-value</th>
<th>Partial F</th>
<th>Partial R²</th>
<th>VIF</th>
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<tbody>
<tr>
<td><strong>Gait Speed over 400 m</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALL; n=101</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model R²=0.32 (p&lt;0.001)</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.483</td>
<td>&lt;0.001</td>
<td>24.5</td>
<td>0.18</td>
<td>1.304</td>
</tr>
<tr>
<td>Leg Strength (N)</td>
<td>0.296</td>
<td>0.005</td>
<td>8.18</td>
<td>0.06</td>
<td>1.471</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.247</td>
<td>0.020</td>
<td>5.61</td>
<td>0.04</td>
<td>1.494</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Women; n=64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model R²=0.24 (p&lt;0.001)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.485</td>
<td>&lt;0.001</td>
<td>17.8</td>
<td>0.24</td>
<td>1.000</td>
</tr>
<tr>
<td>Leg Strength (N)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Men; n=37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model R²=0.39 (p&lt;0.001)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.420</td>
<td>0.005</td>
<td>9.03</td>
<td>0.16</td>
<td>1.087</td>
</tr>
<tr>
<td>Leg Strength (N)</td>
<td>0.356</td>
<td>0.016</td>
<td>6.49</td>
<td>0.12</td>
<td>1.087</td>
</tr>
</tbody>
</table>

Sarcopenia starts to set in around age 45, when muscle mass begins to decline at a rate of about 1 percent per year.

This gradual loss has been associated with protein deficiency, lack of exercise, and increased frailty among the elderly.

The human body reacts to protein deficiency by taking amino acids (the building blocks of proteins) away from muscle tissue and other areas.
The process, in which the body basically metabolizes itself, is called catabolism and leads to muscle loss and weakness.

Currently, the **recommended daily intake is 0.8 grams per kilogram of body weight** (established by the ADA), or 56 grams for a 154-pound person.

However, **very active older individuals might instead benefit from about 1.2 grams per kilogram body weight**.
Health ABC: Adjusted lean mass (LM) loss by quintile of energy-adjusted total protein intake. n = 2066*

Houston D K et al. Am J Clin Nutr 2008;87:150-155
Health ABC – prospective cohort study
LM by DXA; FFQ @ 2 yr clinic visit
• Mean age 74.5 yrs
  • 53% women
  • 35% black
Higher dietary protein intakes were associated with a reduced odds of falling (OR=0.80, 95% CI: 0.60–1.07) and were not associated with the rate of falls over follow-up (RR=0.93, 95% CI: 0.73–1.19).

For those who lost ≥ 5% of their baseline weight, higher intakes of total, animal and plant protein, significantly lower rate of subsequent falls.

Based on results of all available studies that have estimated the minimum protein intake necessary to avoid a progressive loss of lean body mass determined by nitrogen balance, the Food and Nutrition Board recommends protein intake under normal conditions equate to 0.6 g/kg per day according to the estimated average requirements (EAR) and 0.8 g/kg per day according to recommended dietary allowance (RDA) [Intake must be accompanied by an adequate energy supply to achieve optimal protein utilization and should account for 10–35% of total energy consumed.]


<table>
<thead>
<tr>
<th>Food</th>
<th>Amount</th>
<th>Protein (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milk list</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk, whole</td>
<td>1 c</td>
<td>8</td>
</tr>
<tr>
<td>Milk, skim</td>
<td>1 c</td>
<td>8</td>
</tr>
<tr>
<td>Cheese, cheddar</td>
<td>1 oz</td>
<td>7</td>
</tr>
<tr>
<td>Yogurt</td>
<td>1 c</td>
<td>8</td>
</tr>
<tr>
<td><strong>Meat list</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef, lean</td>
<td>1 oz</td>
<td>8</td>
</tr>
<tr>
<td>Chicken breast</td>
<td>1 oz</td>
<td>8</td>
</tr>
<tr>
<td>Luncheon meat</td>
<td>1 oz</td>
<td>5</td>
</tr>
<tr>
<td>Fish</td>
<td>1 oz</td>
<td>7</td>
</tr>
<tr>
<td>Eggs</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Navy beans, cooked*</td>
<td>1/2 c</td>
<td>7</td>
</tr>
<tr>
<td>Peanuts, roasted</td>
<td>1/4 c</td>
<td>9</td>
</tr>
<tr>
<td>Peanut butter</td>
<td>1 tbsp</td>
<td>4</td>
</tr>
<tr>
<td><strong>Vegetable list</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td>1/2 c</td>
<td>2</td>
</tr>
<tr>
<td>Carrots</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Fruit list</strong></td>
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<td></td>
</tr>
<tr>
<td>Banana</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Orange</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pear</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Starch list</strong></td>
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<tr>
<td>Bread, wheat</td>
<td>1 slice</td>
<td>3</td>
</tr>
<tr>
<td>Bran flakes</td>
<td>1 c</td>
<td>4</td>
</tr>
<tr>
<td>Doughnuts</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Macaroni</td>
<td>1/2 c</td>
<td>3</td>
</tr>
<tr>
<td>Macaroni and cheese</td>
<td>1/2 c</td>
<td>9</td>
</tr>
<tr>
<td>Peas, green</td>
<td>1/2 c</td>
<td>4</td>
</tr>
<tr>
<td>Potato, baked</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Sports drinks and bars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gatorade Nutrition Shake</td>
<td>11 oz</td>
<td>18</td>
</tr>
<tr>
<td>Power Bar Protein Plus</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>Endurox4</td>
<td>12 oz</td>
<td>11</td>
</tr>
<tr>
<td><strong>Protein sports supplements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WheyPro</td>
<td>1 oz</td>
<td>22</td>
</tr>
</tbody>
</table>

Protein (grams) may vary slightly from the food exchange lists because these data were derived from food analyses reported by the United States Department of Agriculture.
Aging Effects on Skeletal Muscle

- **Strength training** may be effective in maintaining muscular strength throughout life.

- However, after about age 60, strength levels fall more rapidly, independent of training.

- This is probably influenced by changes in hormones such as testosterone and growth hormone, which appear to decline more dramatically after age 60.

Reduction in circulating concentration of these hormones will result in shift in the balance between muscle protein synthesis (anabolism) and protein breakdown (catabolism).
Possible Benefits of Weight Training for Older Adults

- Better control of symptoms of diabetes, arthritis, osteoporosis, back pain, and depression.
- Prevents falls due to restoration of balance.
- Improved posture and stability.
- Increased flexibility and range of motion.
- Strengthens the bones and reduces risk of fractures.
- Improves muscle strength and endurance.
- Healthy, independent, and functional life.
Aerobic activity recommendation:

- minimum of 30 minutes of moderate-intensity physical activity per day (such as brisk walking) most days of the week
- minimum of 20 minutes of vigorous-intensity physical activity (e.g. jogging) 3 days/week

Resistance Training Activities

- Two days a week, incorporate strength training into your routine.
- Strength training activities, such as weight lifting, maintain and increase muscle strength and endurance.
- A goal to reach towards is completing 6-8 strength training exercises, with 8–12 repetitions per exercise.
Dietary Guidelines for Americans 2005

HHS Toolkit for Health Professionals

• **Getting Older. Living Healthier. Feeling Better.**
  – Consumer Brochure

• **Older Adult Health Fact Sheets (8)**
  – Specific info re healthy diets & phys activity for health professionals

• **Nutrition Service Providers Guide**
  – Assistance materials for planning meals for older adults in group settings

• [www.healthierus.gov/dietaryguidelines/](http://www.healthierus.gov/dietaryguidelines/)

• **National Resource Center on Nutrition, Physical Activity & Aging** - Florida International University

• **US Administration on Aging** [www.aoa.gov](http://www.aoa.gov)

• **Eldercare Locator: [www.eldercare.gov](http://www.eldercare.gov)**
OLDER AMERICANS ACT
NUTRITION PROGRAMS

leadership + choice + innovation + value

= healthy aging