Protein: Amino Acids

Chapter 6
• Contain carbon, hydrogen, oxygen and nitrogen
• Each amino acid has an amino group, an acid group, a hydrogen atom, and a side group.
• It is the side group that makes each amino acid unique.
• Proteins are made from 20 different amino acids, 9 of which are essential.
Examples of Amino Acids

Each amino acid has an unique side groups that result in differences in the size, shape and electrical charge of an amino acid.
The Chemist’s View of Proteins

Amino Acids

Essential amino acids (9)
- Must be supplied by the foods people consume
- Essential amino acids include histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.

Nonessential amino acids (11)
- The body can synthesize
- Nonessential amino acids include alanine, arginine, asparagines, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine.
## Amino Acids

<table>
<thead>
<tr>
<th>Essential Amino Acids</th>
<th>Nonessential Amino Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine (HISS-tuh-deen)</td>
<td>Alanine (AL-ah-neen)</td>
</tr>
<tr>
<td>Isoleucine (eye-so-LOO-seen)</td>
<td>Arginine (ARJ-ih-neen)</td>
</tr>
<tr>
<td>Leucine (LOO-seen)</td>
<td>Asparagine (ah-SPAR-ah-geen)</td>
</tr>
<tr>
<td>Lysine (LYE-seen)</td>
<td>Aspartic acid (ah-SPAR-tic acid)</td>
</tr>
<tr>
<td>Methionine (meh-THIGH-oh-neen)</td>
<td>Cysteine (SIS-teh-een)</td>
</tr>
<tr>
<td>Phenylalanine (fen-il-AL-ah-neen)</td>
<td>Glutamic acid (GLU-tam-ic acid)</td>
</tr>
<tr>
<td>Threonine (THREE-oh-neen)</td>
<td>Glutamine (GLU-tah-meen)</td>
</tr>
<tr>
<td>Tryptophan (TRIP-toe-fan, TRIP-toe-fane)</td>
<td>Glycine (GLY-seen)</td>
</tr>
<tr>
<td>Valine (VAY-leen)</td>
<td>Proline (PRO-leen)</td>
</tr>
<tr>
<td></td>
<td>Serine (SEER-een)</td>
</tr>
<tr>
<td></td>
<td>Tyrosine (TIE-roe-seen)</td>
</tr>
</tbody>
</table>

*These 20 amino acids can all be commonly found in proteins. In addition, other amino acids do not occur in proteins but can be found individually (for example, taurine and ornithine). Some amino acids occur in related forms (for example, proline can acquire an OH group to become hydroxyproline).*
The Chemist’s View of Proteins

- **Proteins**
  - Amino acid chains are linked by peptide bonds in condensation reactions.
    - Dipeptides have two amino acids bonded together.
    - Tripeptides have three amino acids bonded together.
    - Polypeptides have more than two amino acids bonded together.

- **Amino acid sequences**
  - Are all different
  - Allows for a wide variety of possible sequences.
Condensation of Two Amino Acids to Form a Dipeptide

An OH group from the acid end of one amino acid and an H atom from the amino group of another join to form a molecule of water.

A peptide bond (highlighted in red) forms between the two amino acids, creating a dipeptide.
Different Amino Acids Join Together

valine  leucine  tyrosine
Single amino acids with different side chains...

can bond to form...

a strand of amino acids, part of a protein.
Proteins

- Polypeptide - Insulin
The Chemist’s View of Proteins

- Proteins
  - Amino acid sequencing
    - Primary structure – Amino Acid Sequence
      - chemical bonds
    - Secondary structure – electrical attractions
    - Tertiary structure – hydrophilic & hydrophobic
      - Twists and folds
    - Quaternary structure – two or more polypeptides
The Coiling and Folding of a Protein Molecule

A portion of a strand of amino acids.

The strand coils, as this "ribbon" demonstrates.

Coiling the strand. The strand of amino acids takes on a spring-like shape as their side chains variously attract and repel each other.

Folding the coil. Once coiled and folded, the protein may be functional as is, or it may need to join with other proteins or add a vitamin or mineral to become active.
One of the four highly folded polypeptide chains that forms the globular hemoglobin protein.

- Iron
- Heme, the nonprotein portion of hemoglobin, holds iron

The amino acid sequence determines the shape of the polypeptide chain.

Protein shape and function
The Chemist’s View of Proteins

Proteins

Protein **denaturation** is the disruption of the stability of the protein

- The protein uncoils, it loses its shape, and loses its ability to function.

- Proteins can be denatured by heat and acid (stomach acid)

- After a certain point, denaturation cannot be reversed - cooked egg
Protein Digestion in the GI Tract

**Mouth and salivary glands**
- Chewing and crushing moisten protein-rich foods and mix them with saliva to be swallowed

**Stomach**
- Hydrochloric acid (HCl) uncoils protein strands and activates stomach enzymes:
  - Protein \(\rightarrow\) Pepsin, HCl \(\rightarrow\) Smaller polypeptides

**Small intestine and pancreas**
- Pancreatic and small intestinal enzymes split polypeptides further:
  - Poly-peptides \(\rightarrow\) Triptides, dipeptides, amino acids
  - Then enzymes on the surface of the small intestinal cells hydrolyze these peptides and the cells absorb them:
    - Intestinal tripeptidases and dipeptidases \(\rightarrow\) Amino acids (absorbed)

**In the stomach:**
- **Hydrochloric acid (HCl)**
  - Denatures protein structure
  - Activates pepsinogen to pepsin

**Pepsin**
- Cleaves proteins to smaller polypeptides and some free amino acids
- Inhibits pepsinogen synthesis

**In the small intestine:**
- **Enteropeptidase**
  - Converts pancreatic trypsinogen to trypsin
- **Trypsin**
  - Inhibits trypsinogen synthesis
  - Cleaves peptide bonds next to the amino acids lysine and arginine
  - Converts pancreatic procarboxypeptidases to carboxypeptidases
  - Converts pancreatic chymotrypsinogen to chymotrypsin

**Chymotrypsin**
- Cleaves peptide bonds next to the amino acids phenylalanine, tyrosine, tryptophan, methionine, asparagine, and histidine

**Carboxypeptidases**
- Cleave amino acids from the carboxyl ends of polypeptides

**Elastase and collagenase**
- Cleave polypeptides into smaller polypeptides and tripeptides

**Intestinal tripeptidases**
- Cleave tripeptides to dipeptides and amino acids

**Intestinal dipeptidases**
- Cleave dipeptides to amino acids

**Intestinal aminopeptidases**
- Cleave amino acids from the amino ends of small polypeptides (oligopeptides)
Protein Digestion

Key:
- amino acid
- dipeptide
- tripeptide
- polypeptides

1. Protein enters the stomach
2. Proteins are broken down into smaller peptides
3. Peptides are further broken down into amino acids
4. Amino acids are absorbed by intestinal wall cells and transported through the bloodstream to all body's cells.

Bloodstream: The bloodstream transports amino acids to all the body's cells.
Protein Synthesis

- Human body contains an estimated 20,000-25,000 different kinds of proteins.
- Each protein is determined based on their amino acid sequence which is determined by genes.
- The instructions for making every protein in the body are transmitted by the DNA in the nucleus of every cell.
Protein Synthesis
Delivering the Instructions

1. The DNA serves as a template to make strands of messenger RNA (mRNA). Each mRNA strand copies exactly the instructions for making some protein the cell needs.

2. The mRNA leaves the nucleus through the nuclear membrane. DNA remains inside the nucleus.

3. The mRNA attaches itself to the protein-making machinery of the cell, the ribosomes.

D:\Media\Animations\chapter6\0607.html
Protein Synthesis
Lining Up the Amino Acids

1. The DNA serves as a template to make strands of messenger RNA (mRNA). Each mRNA strand copies exactly the instructions for making some protein the cell needs.

2. The mRNA leaves the nucleus through the nuclear membrane. DNA remains inside the nucleus.

3. The mRNA attaches itself to the protein-making machinery of the cell, the ribosomes.

4. Another form of RNA, transfer RNA (tRNA), collects amino acids from the cell fluid. Each tRNA carries its amino acids to the mRNA, which dictates the sequence in which the amino acids will be attached to form the protein strands. Thus the mRNA ensures the amino acids are lined up in the correct sequence.
Protein Synthesis

5 As the amino acids are lined up in the right sequence, and the ribosome moves along the mRNA, an enzyme bonds one amino acid after another to the growing protein strand. The tRNA are freed to return for more amino acids. When all the amino acids have been attached, the completed protein is released.

6 Finally, the mRNA and ribosome separate. It takes many words to describe these events, but in the cell, 40 to 100 amino acids can be added to a growing protein strand in only a second.

http://nutrition.jbpub.com/animations/animations.cfm?id=14&debug=0
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6. Finally, the mRNA and ribosome separate. It takes many words to describe these events, but in the cell, 40 to 100 amino acids can be added to a growing protein strand in only a second. Furthermore, several ribosomes can simultaneously work on the same mRNA to make many copies of the protein.
Protein Synthesis

- DNA template to make mRNA
  - Transcription
- mRNA carries code to ribosome
  - Ribosomes are protein factories
- mRNA specifies sequence of amino acids
  - Translation
  - tRNA
- Sequencing errors
Sequence Errors

Sickle-shaped blood cell       Normal red blood cell

Amino acid sequence of normal hemoglobin:
Val - His - Leu - Thr - Pro - Glu - Glu

Amino acid sequence of sickle-cell hemoglobin:
Val - His - Leu - Thr - Pro - Val - Glu
Protein Synthesis

• Gene Expression -
  o Cells make the type of protein needed for that cell, in the amounts and rates it needs them
  o Nearly all body cells have the genes to make all proteins
    o Each cell makes only the protein it needs
Roles of Proteins

- Building Materials for growth and maintenance
  - Building blocks for most body structures, id, collagen
  - Replaces tissues including the skin, hair, nails, and GI tract lining, muscles, organs
Roles of Proteins

- **Enzymes**
  - Proteins that facilitate the building of substance
  - Proteins that break down substances

The separate compounds, A and B, are attracted to the enzyme's active site, making a reaction likely.

The enzyme forms a complex with A and B.

The enzyme is unchanged, but A and B have formed a new compound, AB.

http://nutrition.jbpub.com/animations/animations.cfm?id=12&debug=0
Roles of Proteins

Hormones

- Messenger molecules
- Some hormones are proteins
- Regulate body processes. An example is insulin

### TABLE 6-2 Examples of Hormones and Their Actions

<table>
<thead>
<tr>
<th>Hormones</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth hormone</td>
<td>Promotes growth</td>
</tr>
<tr>
<td>Insulin and glucagon</td>
<td>Regulate blood glucose (see Chapter 4)</td>
</tr>
<tr>
<td>Thyroxin</td>
<td>Regulates the body’s metabolic rate (see Chapter 8)</td>
</tr>
<tr>
<td>Calcitonin and parathyroid hormone</td>
<td>Regulate blood calcium (see Chapter 12)</td>
</tr>
<tr>
<td>Antidiuretic hormone</td>
<td>Regulates fluid and electrolyte balance (see Chapter 12)</td>
</tr>
</tbody>
</table>

NOTE: Hormones are chemical messengers that are secreted by endocrine glands in response to altered conditions in the body. Each travels to one or more specific target tissues or organs, where it elicits a specific response. For descriptions of many hormones important in nutrition, see Appendix A.
Roles of Proteins

Regulators of **Fluid Balance**
- In critical illness or malnutrition, proteins leak out of the blood vessel and into the tissues
- Fluid accumulates and causes swelling, or edema

**Acid-Base Regulators**
- By accepting and releasing hydrogen, they control acid-base balance
Roles of Proteins

- **Transporters**
  - Carry lipids, vitamins, minerals and oxygen in the body
  - Act as pumps in cell membranes, transferring compounds from one side of the cell membrane to the other
Roles of Proteins

- **Antibodies**
  - Defend against disease
  - Fight bacteria and viruses, that invade the body
  - Provide immunity to fight an antigen more quickly the second time exposure occurs

- **Source of energy and glucose if needed**
  - Will be sacrificed in times of starvation

- **Other Roles**
  - Blood clotting
  - Vision
# Protein Functions in the Body

<table>
<thead>
<tr>
<th>TABLE 6-3 Protein Functions in the Body</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural materials</strong></td>
<td>Proteins form integral parts of most body tissues and provide strength and shape to skin, tendons, membranes, muscles, organs, and bones.</td>
</tr>
<tr>
<td><strong>Enzymes</strong></td>
<td>Proteins facilitate chemical reactions.</td>
</tr>
<tr>
<td><strong>Hormones</strong></td>
<td>Proteins regulate body processes. (Some, but not all, hormones are proteins.)</td>
</tr>
<tr>
<td><strong>Fluid balance</strong></td>
<td>Proteins help to maintain the volume and composition of body fluids.</td>
</tr>
<tr>
<td><strong>Acid-base balance</strong></td>
<td>Proteins help to maintain the acid-base balance of body fluids by acting as buffers.</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>Proteins transport substances, such as lipids, vitamins, minerals, and oxygen, around the body.</td>
</tr>
<tr>
<td><strong>Antibodies</strong></td>
<td>Proteins inactivate foreign invaders, thus protecting the body against diseases.</td>
</tr>
<tr>
<td><strong>Energy and glucose</strong></td>
<td>Proteins provide some fuel, and glucose if needed, for the body's energy needs.</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>The protein fibrin creates blood clots; the protein collagen forms scars; the protein opsins participate in vision.</td>
</tr>
</tbody>
</table>
Protein Metabolism

**Protein Turnover:**
- Proteins are continually made and broken down.
- Amino acids from body proteins mix with dietary protein to form an "amino acid pool" available in cells and blood.
- Remade into new protein.
- Constant process
Protein Metabolism

**Nitrogen Balance:**

- Intake from food (amino acids) balances with nitrogen excretion in feces, urine and sweat
- Nitrogen in = Nitrogen out
- Nitrogen in > nitrogen out = Positive Nitrogen Balance
  - Growing infants, children, pregnant women
  - They are retaining protein in new tissue as they add blood, bone, muscle
- Nitrogen out > Nitrogen in = Negative Nitrogen Balance
  - Starvation, burns, infections, fever
Protein Metabolism

- Using Amino Acids to Make Proteins or Nonessential Amino Acids –
  - Cells can assemble amino acids into the protein needed
  - Can use essential amino acids to make non-essential amino acids

- Using Amino Acids to Make Other Compounds
  - Neurotransmitters are made from the amino acid tyrosine.
  - Tyrosine can be made into the melanin pigment or thyroxin.
  - Tryptophan makes niacin and serotonin.
Protein Metabolism

- **Using Amino Acids for Energy and Glucose**
  - We do not store protein
  - When glucose or fat are not available:
    - Breaks down protein tissue for energy
    - Starvation causes loss of lean body tissue and loss of fat
    - Adequate supply of carbohydrate and fat spares body protein tissue

- **Making fat**
  - Energy and protein exceed needs
  - Carbohydrate intake is adequate
  - Can contribute to weight gain
Proteins in the Body

- A Preview of Protein Metabolism
  - **Deamination** of Amino Acids
    - When amino acids are broken down, nitrogen-containing amino groups are removed- *deamination*
    - Ammonia is released into the bloodstream.
    - Ammonia is converted into *urea* by the liver.
    - Kidneys filter urea out of the blood and it is excreted in urine.
Preview of Protein Metabolism

The deamination of an amino acid produces ammonia (NH₃) and a keto acid.

Given a source of NH₃, the body can make nonessential amino acids from keto acids.
Urea Excretion

- Liver makes **urea** out of Ammonia (NH₃)
- **Urea** travels to the kidneys which filter it out and excrete it in urine

✓ What might accumulate in your blood in liver disease?
✓ What might accumulate in kidney disease?
Protein in Food

**Protein Quality is based on two factors**

- **Digestibility** - amount of amino acids absorbed
  - Other foods consumed
  - Animal vs. plant proteins
    - Animal protein is 90-99%
    - Soy and Legumes is 90%
    - Plant protein is 70-90%

- **Amino acid composition**
  - To make a protein, the cell must have all the need amino acids available
  - Essential amino acid consumption must be adequate
Amino Acid Composition - Limiting AA:

- The liver can make nonessential amino acids from the essential amino acids available.
- If the diet supplies too little of any of the essential amino acids, it is called a limiting amino acid.
  - Lysine, methionine, threonine, tryptophan
- If the diet supplies too little of an essential AA, protein synthesis will be limited.
Protein in Foods

Protein Quality

- Reference Protein
  - Essential AA requirements of preschool-age children

- High-Quality Proteins
  - Contain all the essential amino acids in the amounts required
  - Animal foods contain all the essential amino acids—meats, fish, poultry, eggs, yogurt, milk
  - Plant foods tend to be missing one or more essential amino acids.
Protein Quality

- Complementary proteins
  - Two or more dietary proteins whose amino acid assortments complement each other such that the essential amino acids missing are supplied by the other.

<table>
<thead>
<tr>
<th></th>
<th>Ile</th>
<th>Lys</th>
<th>Met</th>
<th>Trp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legumes</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains</td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Together</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Low quality proteins combined to provide adequate levels of essential amino acids
Health Effects of Protein

- Protein deficiency
  - Slowed growth, impaired brain and kidney function, poor immunity, poor nutrient absorption
- Protein-Energy Malnutrition (PEM)
  - Deficient in protein, energy, or both
  - Most often strikes children
    - Affects 1 in 4 children worldwide under age 5 (25%)
    - Most of the 20,000 children who die each day are malnourished
  - Poor growth in children
  - In adults, wasting and weight loss occur
Protein Malnutrition

- Most prevalent in Africa, Central America, South America, Middle East, East and Southeast Asia
- In the US— the homeless, poverty, elderly, drug and alcohol addiction
- Prevalent in AIDS, tuberculosis, anorexia
- **7.6 million children** under five die in developing countries each year. Malnutrition and hunger-related diseases cause 60 percent of the deaths; *(Source: The State of the World's Children, UNICEF, 2007)*
Protein-Energy Malnutrition

- Acute PEM: recent food deprivation
  - Thin for their height (wasting)
- Chronic PEM: long term food deprivation
  - Short for their age (stunted)
Growth Failure

- Malnutrition
  - Acute and chronic
- **Kwashlorkor (acute)**
  - Wasting form of malnutrition
    - Sudden and recent deprivation of food
    - Muscle wasting
    - Edema in face, limbs, abdomen
    - Fatty liver
    - Skin and hair changes
Growth Failure

- **Marasmus (chronic)**
  - Wasting and stunting form of malnutrition
  - Severe deprivation of food for a long time
  - Diluted cereal drinks and poor quality protein
  - Impaired brain development and learning ability
  - Slow metabolism; lower body temperature
  - Apathetic; may not even cry
  - Growth ceases
  - GI tract deteriorates; cannot absorb food
# Acute and Chronic Malnutrition Compared

<table>
<thead>
<tr>
<th></th>
<th>Acute Malnutrition</th>
<th>Chronic Malnutrition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food deprivation</td>
<td>Current or recent</td>
<td>Long-term</td>
</tr>
<tr>
<td>Physical features</td>
<td>Rapid weight loss</td>
<td>Minimal height gains</td>
</tr>
<tr>
<td></td>
<td>Wasting (underweight for</td>
<td>Stunting (short for age)</td>
</tr>
<tr>
<td></td>
<td>height)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Edema</td>
<td></td>
</tr>
<tr>
<td>World prevalence of</td>
<td>5 to 15%</td>
<td>20 to 50%</td>
</tr>
<tr>
<td>children younger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>than age 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical types</td>
<td>Kwashiorkor</td>
<td>Marasmus</td>
</tr>
</tbody>
</table>
Malnourished Children in India
St. Luke’s Hospital in Kenya
A malnourished child is weighed in Bolosso Sorie, Ethiopia. International Medical Corps’ nutritional programs have seen an enormous spike in the number of malnourished children just in the past few months alone.
Health Effects and Recommended Intakes of Protein

- Malnutrition
  - Infections
    - Lack of antibodies to fight infections
    - Fever
    - Fluid imbalances and dysentery
    - Anemia
    - Heart failure and possible death
- Rehabilitation
  - Rehydration
  - Nutrition intervention must be cautious, slowly increasing protein.
  - Programs involving local people work better.
  - Ready to Use Therapeutic Food
    - Paste made with peanut butter, powered milk, vitamins and minerals
Health Effects and Recommended Intakes of Protein

- Health Effects of Protein
  - Heart Disease
    - Foods high in animal protein also tend to be high in saturated fat.
    - Homocysteine levels increase cardiac risks.
    - Cigarettes, alcohol, coffee
    - Arginine may protect against cardiac risks.
Health Effects and Recommended Intakes of Protein

- Health Effects of Protein
  - Cancer
    - Red meat, processed meat-colon cancer
  - Adult Bone Loss (Osteoporosis)
    - High protein intake associated with increased calcium excretion.
    - May be related to inadequate calcium
    - Inadequate protein intake affects bone health also
Health Effects and Recommended Intakes of Protein

- Health Effects of Protein
  - Weight Control
    - Protein at each meal provides satiety.
    - Adequate protein, moderate fat and sufficient carbohydrate better support weight loss.
  - Kidney Disease
    - High protein intake increases the work of the kidneys.
    - Does not seem to cause kidney disease
Recommended Intakes of Protein

- General recommendation is 10-35% of calories
  - In a 2000 kcal diet: 200-700 kcal or 50-175 grams of protein
- Protein RDA
  - .8 grams per kg of healthy body weight
  - Increases for infants, children, pregnant women
  - Athletes need 1.2-1.7 grams per kg per day
Recommended Intakes of Protein

- Adequate Energy
- Protein Foods
  - 1 ounce of protein = 7 grams
  - 8 ounces of protein = 56 grams
Protein in Foods

- Cooked cereal, rice, noodles, pasta, ½ c: 3 g protein
- Legumes, cooked: ½ c: 7 g protein
- Egg, 1 large: 6 g protein
- Cheese, 1 ½ oz: 11 g protein
- Milk or yogurt, 1 c: 8 g protein
- Poultry, beef, pork or lamb, 3 oz: 26 g protein
- Bread, 1 slice: 2 g protein
- Tofu, 3 oz: 7 g protein
- Cooked vegetables, ½ c: 2 g protein

Average values.
Protein and Amino Acid Supplements

- Muscle work builds protein—not protein supplements
- Food energy spares body protein—carbohydrate and fat
- Protein supplements
  - Whey protein may increase protein synthesis slightly when combined with strength training
  - Do not enhance athletic performance
  - Excess will be stored as fat
Protein and Amino Acids Supplements

- Single amino acids do not occur naturally in food
  - Expensive
  - Less completely digested
  - Single amino acids can be harmful
  - Excess of one can lead to deficiency of another
  - May cause diarrhea

- Lysine and Tryptophan
End of Chapter 6
Protein
MEDITERRANEAN DIET PYRAMID

These foods a few times per month (or somewhat more often in very small amounts)

Red meat

Sweets
Eggs

These foods a few times per week

Poultry

Fish

Cheese and yogurt

Olive oil

Beans, other legumes, and nuts

Vegetables

Fruits

Bread, pasta, rice, couscous, polenta, bulgur, other grains, and potatoes

These foods daily

a The authors of this pyramid also recommend regular physical exercise and moderate consumption of wine.

b Other oils rich in monounsaturated fats, such as canola or peanut oil, can be substituted for olive oil. People who are watching their weight should limit their oil consumption.