SP.235 / ESG.SP235 Chemistry of Sports
Spring 2009

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SP.235 - Chemistry of Sports

Week 2-on-line reading

Topics to cover:

Chemical Review

Anatomy and Physiology of the Basic systems of your body: focusing on Cardiovascular, Respiratory, Nervous system, skeletal , muscular

The Human Body

- We are going to review some anatomy and physiology
- Anatomy - is the study of the structure of body parts. It is also the relationship among these parts. The heart, for instance, consists of chambers, valves and associated blood vessels
- Physiology - is the study of the function of body parts. The parts of the heart, for instance, work together to pump the blood throughout the body

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Level of organization

- Atom
- Molecule
- Organelle
- Cell
- Tissue
- Organ
- Organ systems
- Organism

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Level of organization

- Atom- matter consists of elements. The most common elements in the body are hydrogen, carbon, oxygen, and nitrogen.
- Molecule- atoms bond together to form molecules. The human body consists of 65 % water (H_2O). Smaller molecules can bond together to form polymers. For instance, amino acids are the monomeric unit of proteins
- Organelle -Molecules compose the parts of the cell called organelles which carry out specific function. For instance glucose is metabolized in the mitochondria
- Cell - smallest unit displaying the properties of life. In humans, cells tend to specialize. For instance muscle cells are involved in locomotion

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Level of organization

- Tissue - similar cells function together in a tissue. Muscle cells work together in skeletal muscle tissue. These cells contract, producing body movement
- Organ- two or more tissues work together in an organ. The heart consists of several tissue types
- Organ systems-organs with related functions are part of the same organ system. The circulatory system consists of the heart and blood vessels
- Organism - all the organ systems make up the organism. The organ systems of the human body consist of the nervous, circulatory, respiratory and digestive systems.

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Anatomical Terms

- Directional terms:
  – Superior/Inferior - superior close to the head
  Inferior is closer to the feet.
  – Anterior/Posterior -Anterior (ventral) closer to the front of body. Posterior (dorsal) closer to the back.
  – Medial/Lateral - Medial refers to a part that is closer to an imaginary midline passing vertically through the body. Lateral refers to a part that is farther from the midline.
  – Proximal/Distal - Proximal refers to a part of a limb that is closer to the trunk (torso) of the body. Distal refers to a limb part that is farther from the trunk.

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Other Anatomical Terms

- Superficial - closer to the surface of the body
- Deep - farther away from the surface of the body
- Parietal -referring to the wall of a body cavity
- Visceral - referring to an organ within the body cavity

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Anatomical points of reference

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See, for example:
http://en.wikipedia.org/wiki/Anatomical_terms_of_location

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Anatomical points of reference

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See, for example:
http://en.wikipedia.org/wiki/Anatomical_terms_of_location

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Planes and Sections of the body

- Sagittal Plane - passes through the body longitudinally, dividing it into left and right regions.
- Coronal (Frontal) Plane - passes through the body longitudinally dividing it into anterior and posterior regions
- Transverse plane - passes through the body horizontally, dividing it into superior and inteferior regions.

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Body Cavities

- Dorsal Cavity -
  - cranial cavity (superior bones of the skull and contains the brain)
  - spinal cavity - vertebrae (which contain the spinal cord)
- Ventral Cavity
  - Thoracic -superior to the diaphragm - subdivided into left and right pleural cavity (which contain the lungs), -
  - Mediastinum (space between the pleural cavities and contains the trachea, esophagus, thymus gland and heart)
  - Abdominopelvic -
    - larger abdominal portion contains the liver, gallbladder, stomach, small intestine and most of the large intestine
    - Smaller pelvic portion contains the large intestine, bladder and reproductive organs.

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Organ Systems

- Skeletal system
- Muscular System
- Circulatory System
- Respiratory System
- Nervous system
- Digestive System
- Endocrine System
- Integumentary system
- Urinary System
- Reproductive System

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Organ Systems

- Skeletal system- bones and articulations (joints)
- Muscular System -skeletal muscles
- Circulatory System -blood, heart and blood vessels (includes the lymphatic system)
- Respiratory System- nose, pharynx, larynx, trachea, primary bronchi, secondary bronchi, bronchioles, alveolar ducts, alveoli
- Nervous system
  - central nervous system is the brain and spinal cord
  - Peripheral Nervous system -cranial and spinal nerves

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Organ Systems

- Digestive System -oral cavity, pharynx, esophagus, stomach, small intestine, large intestine, rectum plus salivary glands, teeth, liver, gallbladder and pancreas
- Endocrine System -pituitary, thyroid, parathyroids, adrenal, pancreas and gonads
- Integumentary system -skin and accessory organs
- Urinary System -kidneys, ureters, urinary bladder and urethra
- Reproductive System
  - Male - pair of testes, ducts, glands and external genitalia
  - Female -pair of ovaries, two uterine tubes, uterus, vagina and external genitalia

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Homeostasis

- This is the maintenance of relatively constant conditions of internal environment of the body.
- Internal environment is tissue fluid (blood) that bathes the cells
- Characteristics
  - Temperature - 37 ^{0}C
  - Blood sugar - 100 mg per 100 mL of blood
  - pH of blood - at 7.4

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Back to the atomic scale

How much of general chemistry do we really remember?

Water

- Formula is 2 Hydrogens and 1 oxygen
- 65 % of the human body is water
- Need to make sure that you maintain sufficient water in you system so that you don't get dehydrated

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Solution chemistry

- Acid -proton donor
- Base -proton acceptor
- pH = - log[H_3O^+]
  - Below pH = 7 - acidic
  - At pH = 7 -neutral
  - Above pH = 7 - basic
- Buffer
  - solution that stabilizes the pH of a solution
  - Consists of a weak acid and its conjugate or weak base and its conjugate
- Salt - a compound that dissolves completely in water to form a cation and anion

$$\underset{\text{Acid}}{HA\ (aq)} + \underset{\text{Base}}{B^-(aq)} \rightleftharpoons \underset{\text{Conj. Base}}{A^-(aq)} + \underset{\text{Conj. Acid}}{HB\ (aq)}$$

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Organic Macromolecules

- polysaccharides
- proteins
- nucleic acids
- lipids

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See Fig. 3.2 in [Purves].

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Macromolecules

- Proteins, nucleic acids and polysaccharides are formed by covalent bonds between monomers
- lipids aggregate due to hydrophobic interactions and not covalent interactions

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See Table 3.1 in [Purves].

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Formation of macromolecules

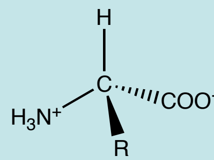
- Macromolecules are made from smaller monomers by means of a **condensation** or **dehydration reaction** in which an OH from one monomer is linked to an H from another monomer.
- Energy must be added to make or break a polymer.
- The reverse reaction, in which polymers are broken back into monomers, is a called a **hydrolysis reaction**.

Proteins: Polymers of Amino Acids

- **Proteins** are polymers of **amino acids**. They are molecules with diverse structures and functions.
- Each different type of protein has a characteristic amino acid composition and order.
- Proteins range in size from a few amino acids to thousands of them.
- Folding is crucial to the function of a protein and is influenced largely by the sequence of amino acids.
- Functions of proteins include support, protection, catalysis, transport, defense, regulation, and movement. They sometimes require an attached prosthetic group.

Proteins: Polymers of Amino Acids

- An amino acid has four groups attached to a central carbon atom:
  - A hydrogen atom
  - An **amino group** (NH_3^+)
  - The acid is a **carboxyl group** (COO–).
  - Differences in amino acids come from the side chains, or the **R groups.**
  - It is an L-amino acid, α amino acid or an S-amino acid



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Proteins: Polymers of Amino Acids

- Twenty naturally occurring amino acids are found in proteins.
- Amino acids can be classified based on the characteristics of their R groups.
  - Five have charged hydrophilic side chains.
  - Five have polar but uncharged side chains.
  - Seven have nonpolar hydrophobic side chains.
  - Cysteine has a terminal disulfide (—S—S—).
  - Glycine has a hydrogen atom as the R group.
  - Proline has a modified amino group that forms a covalent bond with the R group, forming a ring.

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Amino acids structure

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copyright restrictions.
See Table 3.2a in [Purves].

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Amino acids structure

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See Table 3.2b & c in [Purves].

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Amino acids structure

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See Table 3.2d in [Purves].

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Proteins: Polymers of Amino Acids

- Amino acids are covalently bonded together by peptide linkages.

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Proteins: Polymers of Amino Acids

- Proteins are also called **polypeptides**. A dipeptide is two amino acids long; a tripeptide, three. A oligopeptide is 4 to 10ish peptides long. A polypeptide is multiple amino acids long.
- Polypeptide chains of proteins are folded into specific three-dimensional shapes. Primary, secondary, tertiary, and quaternary structures are possible.

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Proteins: Polymers of Amino Acids

- The primary structure of a protein is the sequence of amino acids bonded by peptide linkages.
- The peptide backbone consists of repeating units of atoms: N—C—C—N—C—C. Enormous numbers of different proteins are possible.

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See Figure 3.6a in [Purves].

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Proteins: Polymers of Amino Acids

- Secondary structures are maintained by hydrogen bonds between atoms of the amino acid residues.
- The two common secondary structures are the **α helix** and the **β pleated sheet**.
- The α helix is a right-handed coil.
- The peptide backbone takes on a helical shape due to hydrogen bonds.
- The R groups point away from the peptide backbone.
- Fibrous structural proteins have α-helical secondary structures, such as the keratins found in hair, feathers, and hooves.

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See Figure 3.6b in [Purves].

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Proteins: Polymers of Amino Acids

- The tertiary structure is generated by bending and folding of the polypeptide chain.
- The primary determinant of the tertiary structure is the interaction between R groups.
- Other factors can include the location of **disulfide bridges**, which form between cysteine residues.

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Disulfide bridges

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Tertiary Structure

- Other factors determining tertiary structure:
  - The nature and location of secondary structures
  - Hydrophobic side-chain aggregation and van der Waals forces, which help stabilize them
  - The ionic interactions between the positive and negative charges deep in the protein, away from water

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Proteins: Polymers of Amino Acids

- The quaternary structure is the arrangement of polypeptides in a single functional unit consisting of more than one polypeptide subunit.

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See Figure 3.8 in [Purves].

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Proteins: Polymers of Amino Acids

- Shape is crucial to the functioning of some proteins:
  - Enzymes need certain surface shapes in order to bind substrates correctly.
  - Carrier proteins in the cell surface membrane allow substances to enter the cell.
  - Chemical signals such as hormones bind to proteins on the cell surface membrane.
- The combination of attractions, repulsions, and interactions determines the right fit.

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Proteins: Polymers of Amino Acids

- Weak chemical interactions are important in the binding of proteins to other molecules.

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Proteins: Polymers of Amino Acids

- Proteins denatured by heat, acid, or chemicals lose tertiary and secondary structure and biological function.

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Carbohydrates: Sugars and Sugar Polymers

- All carbohydrates contain carbon bonded to H and OH groups.
- **Carbohydrates** are carbon molecules with hydrogen and hydroxyl groups.
- They act as energy storage and transport molecules.
- They also serve as structural components.

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Carbohydrates: Sugars and Sugar Polymers

- There are four major categories of carbohydrates:
  - **Monosaccharides**
  - **Disaccharides**, which consist of two monosaccharides
  - **Oligosaccharides**, which consist of between 3 and 20 monosaccharides
  - **Polysaccharides**, which are composed of hundreds to hundreds of thousands of monosaccharides
- Hexoses are monosaccharides that contain six carbon atoms. Review
- Dextrose is just another name for the ring form of glucose.

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Carbohydrates: Sugars and Sugar Polymers

- The general formula for a carbohydrate monomer is multiples of CH_2O, maintaining a ratio of 1 carbon to 2 hydrogens to 1 oxygen.
- During the **polymerization**, which is a condensation reaction, water is removed.
- Carbohydrate polymers have ratios of carbon, hydrogen, and oxygen that differ somewhat from the 1:2:1 ratios of the monomers.

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Carbohydrates: Sugars and Sugar Polymers

- All living cells contain the monosaccharide glucose ($C_6H_{12}O_6$).
- Glucose exists as a straight chain and a ring, with the ring form predominant.
- The two forms of the ring, α-glucose and β-glucose, exist in equilibrium when dissolved in water.

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See Figure 3.13 in [Purves].

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Carbohydrates: Sugars and Sugar Polymers

- Different monosaccharides have different numbers or different arrangements of carbons.
- Most monosaccharides are optical isomers.
- **Hexoses** (six-carbon sugars) include the structural isomers glucose, fructose, mannose, and galactose.
- **Pentoses** are five-carbon sugars.

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Structures of Sugars

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See Figure 3.14 in [Purves].

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Carbohydrates: Sugars and Sugar Polymers

- Monosaccharides are bonded together covalently by condensation reactions. The bonds are called **glycosidic linkages**.
- Disaccharides have just one such linkage: sucrose, lactose, maltose, cellobiose.
- Maltose and cellobiose are structural isomers.
- Glycosidic linkages may have either α or β orientation in space. They covalently link monosaccharides into larger units.

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Formation of the glycosidic linkage in sugars

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Carbohydrates: Sugars and Sugar Polymers

- Many proteins found on the outer surface of cells have oligosaccharides attached to the R group of certain amino acids, or to lipids.
- The human ABO blood types owe their specificity to oligosaccharide chains.

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Carbohydrates: Sugars and Sugar Polymers

- Polysaccharides are giant polymers of monosaccharides connected by glycosidic linkages.
- **Cellulose** is a giant polymer of glucose joined by β-1,4 linkages.
- **Starch** is a polysaccharide of glucose with α-1,4 linkages.

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Molecular structure of cellulose.
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See Figure 3.16a in [Purves].

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Molecular structure of starch and glycogen.
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See Figure 3.16a in [Purves].

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Carbohydrates: Sugars and Sugar Polymers

- Cellulose, a polymer, is formed by glucose units linked by β-glycosidic linkages between carbons 1 and 4.
- Starches are formed by α-glycosidic linkages between carbons 1 and 4 and are distinguished by amount of branching through glycosidic bond formation at carbon 6.
- Glycogen contains α-1,4 glycosidic linkages and is highly branched.

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Carbohydrates: Sugars and Sugar Polymers

- Carbohydrates are modified by the addition of functional groups:
  - Glucose can acquire a carboxyl group (—COOH), forming glucuronic acid.
  - Phosphate added to one or more hydroxyl (—OH) sites creates a **sugar phosphate** such as fructose 1,6-bisphosphate.
  - Amino groups can be substituted for —OH groups, making **amino sugars** such as glucosamine and galactosamine.
  - A derivative of the amino sugar glucosamine

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Structures of carbohydrates

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See Figure 3.17 in [Purves].

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Macromolecules Nucleic Acids: Informational

- **Nucleic acids** are polymers that are specialized for storage and transmission of information.
- Two types of nucleic acid are **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid).
- DNA encodes hereditary information and transfers information to RNA molecules.
- The information in RNA is decoded to specify the sequence of amino acids in proteins.

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Nucleic Acids: Informational Macromolecules

- Nucleic acids are polymers of nucleotides consisting of a phosphate group, a sugar, and a nitrogen-containing base. The DNA bases are adenine, guanine, cytosine, and thymine. In RNA uracil substitutes for thymine.

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See Figure 3.24 in [Purves].

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Nucleic Acids: Informational Macromolecules That Can Be Catalytic

- Nucleotides have other important roles:
  - The ribonucleotide ATP acts as an energy transducer in many biochemical reactions.
  - The ribonucleotide GTP powers protein synthesis.
  - cAMP (cyclic AMP) is a special ribonucleotide that is essential for hormone action and the transfer of information by the nervous system.

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Lipids: Water-Insoluble Molecules

- Lipids can form gigantic structures, but these aggregations are not chemically macromolecules because individual units are not linked by covalent bonds.
- **Lipids** are insoluble in water.
- This insolubility results from the many nonpolar covalent bonds of hydrogen and carbon in lipids.
- Lipids aggregate away from water, which is polar, and are attracted to each other via weak, but additive, van der Waals forces.

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Lipids: Water-Insoluble Molecules

- Roles for lipids in organisms include:
  - Energy storage (fats and oils)
  - Cell membranes (phospholipids)
  - Capture of light energy (carotinoids)
  - Hormones and vitamins (steroids and modified fatty acids)
  - Thermal insulation
  - Electrical insulation of nerves
  - Water repellency (waxes and oils)

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Lipids: Water-Insoluble Molecules

- Fats and oils store energy.
- Fats and oils are **triglycerides**, composed of three fatty acid molecules and one glycerol molecule.
- **Glycerol** is a three-carbon molecule with three hydroxyl (—OH) groups, one for each carbon.
- **Fatty acids** are long chains of hydrocarbons with a carboxyl group (—COOH) at one end.

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Lipids: Water-Insoluble Molecules

- Fats and oils are composed of three fatty acids covalently bonded to a glycerol molecule by ester linkages.

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See Figure 3.18 in [Purves].

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Lipids: Water-Insoluble Molecules

- **Saturated fatty acids** have only single carbon-to-carbon bonds and are said to be saturated with hydrogens.
- Saturated fatty acids are rigid and straight, and solid at room temperature. Animal fats are saturated.
- **Unsaturated fatty acids** have at least one double-bonded carbon in one of the chains —the chain is not completely saturated with hydrogen atoms.
- The double bonds cause kinks that prevent easy packing. Unsaturated fatty acids are liquid at room temperature. Plants commonly have unsaturated fatty acids.

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Lipids: Water-Insoluble Molecules

- Phospholipids have a hydrophobic hydrocarbon "tail" and a hydrophilic phosphate "head."

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See Figure 3.20a in [Purves].

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Lipids: Water-Insoluble Molecules

- In water, the interactions of the hydrophobic tails and hydrophilic heads generate a phospholipid bilayer two molecules thick. The head groups are directed outward, interacting with surrounding water. Tails are packed in the interior.

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Lipids: Water-Insoluble Molecules

- Carotenoids trap light energy in green plants. β-Carotene can be split to form two molecules of vitamin A, a lipid vitamin.

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Lipids: Water-Insoluble Molecules

- **Steroids** are signaling molecules.
- Steroids are organic compounds with a series of fused rings.
- The steroid cholesterol is a common part of animal cell membranes.
- Cholesterol is also is an initial substrate for synthesis of the hormones testosterone and estrogen.

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Structures of Steroids

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copyright restrictions.
See Figure 3.23 in [Purves].

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Lipids: Water-Insoluble Molecules

- Some lipids are vitamins: small organic molecules essential to health.
- Vitamin A is important for normal development, maintenance of cells, and night vision.
- Vitamin D is important for absorption of calcium in the intestines.
- Vitamin E, an antioxidant, protects membranes.
- Vitamin K is a component required for normal blood clotting.

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Lipids: Water-Insoluble Molecules

- Vitamins, required for normal functioning, must be acquired from the diet.
- There are essential and non-essential vitamins
- Essential vitamins are those which have to be acquired from the diet
- Non-essential vitamins can be synthesized in your body

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Eukaryotic Cellular Structure

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Eukaryotic Cellular Structure

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The Nucleus is Enclosed by a Double Membrane

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Some important subcellular structures

- Nucleus - houses DNA and it is where RNA gets synthesized before it gets transported out of the nucleus to the:
- Ribosomes - where protein synthesis occurs
- Cytoplasm - where glycolysis occurs
- Mitochondria - where the majority of energy gets metabolized (pyruvate oxidation, citric acid cycle, electron transport chain)

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A Mitochondrion Converts Energy from Fuel Molecules into ATP

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A Mitochondrion Converts Energy from Fuel Molecules into ATP

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Tissues

- Four principle types of tissues:
  - Epithelial tissue
  - Connective tissue
  - Nervous tissue
  - Muscle tissue

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Tissues

- Four principle types of tissues:
  - Epithelial tissue -covers the free surfaces of the body
  - Connective tissue
  - Nervous tissue
  - Muscle tissue

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Tissues

- Four principle types of tissues:
  - Epithelial tissue
  - Connective tissue- consists of cells dispersed population of cells embedded in an extracellular matrix that they secrete. Examples of the extracellular matrix are protein fibers (collagen, elastin), cartilage, bone, adipose tissue, and blood.
  - Nervous tissue
  - Muscle tissue

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Connective tissue

- Collagen
  - most abundant protein in the human body
  - Gives the connective tissue of skin, tendons, and ligaments resistance to stretch
  - Gives organs a netlike framework for their shape and structural strength.
- Elastin
  - Can be stretched to to several times its resting length and then recoil.
  - Found in tissues that are regularly stretched (walls of lungs and large arteries)
  - Gradual loss of elastin fibers with age causes the gradual loss of resiliency of the skin (sagging)

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Connective tissue

- Cartilige and bone - give structural strength
- Cartilige
  - Network of collagen fibers is embedded in a flexible matrix consisting of a protein-carbohydrate complex
  - Resistant to compressive forces
- Bone
  - Network of collagen fibers but is hardened by the deposition of the mineral calcium phosphate

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Connective tissue

- Adipose Tissue
  - Loose connective tissue that includes adipose cells, which form and store droplets of lipids
  - Major source of stored energy
  - Serves to cushion organs and layers of adipose tissue under the skin can provide a barrier to heat loss
- Blood
  - Cells dispersed in an extensive extrallular matrix, the blood plasma
  - Contains an abundance of proteins and cellular elements.

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Composition of Blood

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copyright restrictions.
See Figure 49.15 in [Purves].

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Tissues

- Four principle types of tissues:
  - Epithelial tissue
  - Connective tissue
  - Nervous tissue- neurons have the ability to send signals
  - Muscle tissue

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See Figure 44.2 in [Purves].

Cell body contains the nucleus and most cell organelles. It integrates the information from the dentrites and initiates the nerve impulses at the beginning of the axon

Axon conducts nerve impulses away from the cell body

Axon terminals synapse with a target cell

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Nervous Systems: Cells and Functions

- The **cell body** contains the nucleus and most of the cell's organelles.
- Many projections sprout from the cell body; most of them are **dendrites**, which bring information from other neurons or sensory cells to the cell body. The **axon** usually carries information away from the cell body.
- Axons conduct information to **target cells**, which can be other neurons, muscle cells, or gland cells.
- At its end, the axon divides into many fine nerve endings. At the tip of each nerve ending is a swelling called the **axon terminal**.
- The axon terminal is positioned very close to the target cell.
- At the axon, terminal nerve impulses cause the release of **neurotransmitters** (chemical messengers) into the **synapse**.

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Tissues

- Four principle types of tissues:
  - Epithelial tissue
  - Connective tissue
  - Nervous tissue
  - Muscle tissue -muscle cells have the ability to shorten their length. There are three types skeletal, smooth and cardiac

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Muscles of the human body

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copyright restrictions.
Diagram of the major muscles,
front and rear view of human body.

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Types of Vertebrate Muscle tissues

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See Figure 47.1 in [Purves].

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Types of Vertebrate Muscle tissues

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See Figure 47.1 in [Purves].

Smooth Muscle

- Provides contractile force for most of our internal organs (which are under the control of our autonomic nervous system)
- Moves food through the digestive tract, controls the flow of blood through blood vessels and empties the urinary bladder.
- Cells are usually long and spindle-shaped
- Cells arranged in sheets and individual cells in a sheet are in electrical contact with one another through gap junctions. The action potential generated in the membrane of one smooth muscle cell can spread to all the cells in the sheet of tissue (creates a coordinated contraction)

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Smooth Muscles

- Cells are sensitive to being stretched.
- For instance when food is swallowed, the plasma membrane is stretched in one location of the digestive tract, and this causes the membranes of the stretched cells to depolarize, reach threshold and fire action potentials, which cause the cells to contract.

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See Experiment: Figure 47.2 in [Purves].

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Apply acetylchloine

Remove acetylchloine

Apply norepinephrine

Remove norepinephrine

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See Experiment: Figure 47.2 in [Purves].

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Cardiac cells

- These cells are striated because of the regular arrangement of their actin and myosin filaments
- Cells also branch and the branches of adjoining cells interdigitate into a meshwork that allows cardiac muscle to resist tearing.
- Intercalated discs provide strong mechanical adhesions between adjacent cells.

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Cardiac Muscle Cells

- Actin and myosin molecules are organized into microfilaments consisting of two or more molecules
- Actin filaments consist of a twisted chain of actin protein molecules
- Myosin filaments are bundles of many myosin protein molecules
- When contraction is is triggered, the actin and myosin filaments slide past each other in a telescoping fashion (which is the mechanism by which muscle cells contract)
- Muscle cell plasma membranes can generate action potentials and it is these action potentials that trigger the contractile machinery.

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Cardiac Muscle Cells

- Pacemaker cells initiate the rhythmic contractions of the heart
- Heartbeat is myogenic (generated by the heart muscle itself)
- The autonomic nervous system modifies the rate of the pacemaker cells but is not essential for their continues rhythmic contractions
- A heart removed from an animal continues to beat with no input from the nervous system (this is why you can transplant a heart from one individual to another)

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Structure of skeletal muscle

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See Figure 47.1 in [Purves].

- There are more than 600 skeletal muscles in the human body
- Functions
  - Movement (attached to the bones)
  - Heat production
  - posture

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Structure of skeletal muscle

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copyright restrictions.
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- These muscles carry out voluntary movements
- Striated muscle because of its striped appearance
- Large multinucleated (due to fusion with of many individual cells)

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Structure of skeletal muscle

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See Figure 47.3 in [Purves].

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Structure of skeletal muscle

M band
Z line
I band

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copyright restrictions.
See Figure 47.3 in [Purves].

Z line
Actin filament
Titin filament
Myosin filament
M band

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Skeletal Muscles

- Sarcomeres are a unit of contraction and consist of units of overlapping filaments of actin and myosin, which create a distinct band pattern.
- As the muscle contracts, the sarcomeres shorten and the appearance of the band pattern changes.

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Skeletal Muscles

- Each Sarcomere is bounded by Z lines which are structures that anchor the thin actin filaments
- A band -which contains all the myosin filaments
- H zone and I band which appear light are regions where actin and myosin filaments do not overlap in the relaxed muscle
- Dark stripe in the H zone is called the M band and it contains proteisn that help hold the myosin filaments in their arrangement
- Titan is long polypeptide that runs from Z line to Z line and through the myosin bundle. It has the properties of a bungee cord - very stretchable

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Muscle contraction

- When the muscle contracts the sarcomere shortens
- The H zone and the I band become much narrower and the Z lines move toward the A bond as if the actin filaments were sliding into the region occupies by the myosin filaments

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Actin-Myosin interactions cause filaments to slide

Tropomyosin

Troponin

Actin filament

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See Figure 47.4 in [Purves].

Actin monomer

Myosin

- Myosin molecule consist of two long polypeptide chains coiled together each ending in a large globular head
- Actin filament consists of a helical arrangement of two chains of actin monomers twisted together. Twisting around the actin filaments is a protein tropomyosin and at regular intervals, troponin is found

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Actin-Myosin interaction

- Myosin heads have sites that can bind to actin and thereby form cross-bridges between the myosin and the actin filaments
- Myosin also bind ATP and hydrolyzes ATP.
- Hydrolysis of ATP provides the energy to change the conformation and therefore the orientation of the myosin head.
- Muscles require ATP to stop contracting. As long as there is a constant supply of ATP, the muscle will have the ability to stop contracting (when you die there is no ATP, so you are in a state on constant contraction, rigor mortis)

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Muscle contractions

- Muscle contractions are initiated by action potentials from motor neurons
- Axons of motor neurons are generally highly branched and can synapse with up to a hundred muscle fibers each (which consist of a motor unit)
- Transverse tubules (are called T tubules) which are in close contact with Sarcoplasmic reticulum (bascially a network of membrane-enclosed compartments) from which Ca^{+2} ions are taken up (which are from the sarcoplasm (or cytoplasm of the muscle fiber).

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T Tubules in action

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See Figure 47.5 in [Purves].

1. An action potential (black arrow) arrives at the motor neuron terminal
2. The muscle fiber plasma membrane generates an action potential that spreads down T tubules
3. Which causes the release of Ca^{+2} stored in the sarcoplasmic reticulum
4. Release Ca^{+2} stimulates muscle contraction

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Muscle contraction

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See Figure 47.6 in [Purves].

1. Ca^{+2} is released from the sarcoplasmic reticulum
2. Ca^{+2} in the sarcoplasm binds troponin and exposes myosin-binding sites on the actin filament
3. Myosin heads bind to actin; ADP is released
4. In the power stroke, the myosin head changes conformation; filaments slide past one another
5. ATP binds to myosin, causing it to release actin
6. ATP is hydrolyzed and the myosin head returns to its resting conformation
7. If Ca^{+2} is returned to the sarcoplasmic reticulum, the muscle relaxes

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More muscle terminology

- Muscle twitch is due to the spread of the action potential through the T tubule system and is the minimum unit of contraction
- A twitch can be measured in terms of the tension (or force) is generates.
- A single action potential stimulates a single twitch, but depending on how many muscle fibers are in its motor units, the ultimate force that it generates can vary. For instance, fine motor skills (moving a single finger) requires the movement of a few muscle fibers, but in a muscle that produces large forces (as seen in a biceps), much more muscle fibers are involved.

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Twitches

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1. A stimulus elicits a twitch, the minimum unit of contraction of a muscle fiber
2. Two twitches in quick succession have a summed effect
3. Muscles relax when stimulus stops

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Tetanus

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copyright restrictions.
See Figure 47.7b in [Purves].

1. Eight summed twitches bring the muscle fiber to maximum contraction, known as tetanus
2. Tetanus is sustained by a high rate of stimulation
3. Muscles relax when stimulus stops

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Muscle tone

- Muscle tone comes from the activity of a small but changing number of motor units in a muscle; at any one time, some of the muscle fibers are contracting and others are relaxed.
- Muscle tone is constantly being readjusted by the nervous system

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Muscle Strength and Performance

- Two types of muscle fibers:
  - Slow-twitch fibers (red muscle)
  - Fast-twitch fibers (white muscle)

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Slow Twitch Fibers

- lower ATPase activity so they can develop tension more slowly and maintain it over a longer period of time.
- The have lots of myoglobin and mitochondria and are well supplied with blood vessels.
- Have increased capacity for oxidative metabolism (metabolizing glucose to H_2O and CO_2 using O_2)
- High reserves of fuel (glycogen and fat)
- These are good for long-term aerobic work (for instance, swimmers, bicyclists and long-distance runners)

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Fast Twitch Muscles

- Fewer mitochondria, little or no myoglobin and fewer blood vessels (think breast meat of a chicken)
- Develop maximum tension more rapidly than slow-twitch fibers and can put the energy of ATP to work very rapidly, but the fibers can not replenish the ATP quickly enough to maintain contraction
- These fibers are especially good for short-term work that requires maximum strength. (for instance champion weight lifters and sprinters)

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Two types of muscle fibers

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See Figure 47.8 in [Purves].

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Organ systems

- Cardiac
- skeletal

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Cardiac System

- Job is to pump nutrients and oxygen to the cells of the body and remove waste

Image removed due to copyright restrictions.
Human body cardiac system diagram.

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Cardiac system

Image removed due to copyright restrictions.
See Figure 49.3 left in [Purves].

- Vessels shown in red bring oxygenated blood form the lungs to the left heart which pumps it to the rest of the body
- Vessels shown in blue bring deoxygenated blood from the body to the right heart, which pumps it to the lungs for oxygenation

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Human Heart

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See Figure 49.3 in [Purves].

1. Deoxygenated blood from the tissues of the body enters the right atrium
2. And flows through an atrioventricular valve into the right ventricle
3. The right ventricle pumps the blood into the pulmonary circuit
4. From the pulmonary circuit, the blood returns to the left atrium
5. And flows through an atrioventricular valve into the left ventricle
6. The left ventricle pumps blood into the systemic circuit

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Circulatory system

- Oxygenated and deoxygenated blood can not mix; therefore the systemic circuit is always receiving blood with the highest oxygen content
- Respiratory gas exchange is maximized because the blood with the lowest oxygen content and highest CO_2 content is sent to the lungs
- Separate systemic and pulmonary circuits can operate at different pressures
- Tissues have high nutrient demands and thus a very high density of the smallest vessels, the capillaries.

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The Cardiac cycle

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See Figure 49.4 in [Purves].

1. The atria contract
2. "lub" the ventricles contract, the atrioventricular valves close and pressure in the ventricles builds up until the aortic and pulmonary valves open
3. Blood is pumped out of the ventricles and into the aorta and pulmonary artery
4. "Dub" the ventricles relax; pressure in the ventricles falls at the end of systole, and since pressure is now greater in the aorta, the aortic and pulmonary valves slam shut
5. The ventricles fill with blood

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Anatomy of Blood Vessels

Because veins operate under low pressure, some veins have valves to prevent backflow of blood

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See Figure 49.10 in [Purves].

122

What happens in the capillary beds?

- As blood flows through the capillary, CO_2 diffuses into the plasma and is converted into bicarbonate ions

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See Figure 48.14 in [Purves].

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What happens in the capillary beds?

- There is a substantial rise in HCO_3^{-1} concentration as blood flows through the capillary
- When the person is at rest, the increasing HCO_3^{-1} concentration can cause the osmotic pressure of the blood at the venous end to be 30 mm Hg higher than at the arterial end, and during strenuous exercise this difference can be hundreds of mm Hg.

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What happens in the capillary beds?

- All capillaries are permeable to O_2, CO_2, glucose, lactate and small ions such as Na^{+1} and Cl^{-1}.
- The capillaries of the brain are very selective to what can pass through them (blood-brain barrier) and the capillaries of the digestive tract and kidneys are non-selective.

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What happens when you exercise?

- When you walk or run, your legs acts as auxiliary vascular pumps, returning blood to the heart from the veins of the lower body
- As a greater volume of blood is returned to the heart, the heart contracts more forcefully and its pumping action is enhanced
- The strengthening of the heart beat is due to a property of cardiac muscle cells described by the Frank-Starling law: if cells are stretched, as they are when the volume of returning blood increases, they contract more forcefully.
- The actions of breathing also help return venous blood to the heart. The ventilatory muscles create negative pressure that pulls air into the lungs and it also pulls blood toward the chest, increasing venous return to the right atrium.
- In addition, some of the largest veins closest to the heart contain smooth muscle that contracts at the onset of exercise. The contraction can rapidly increase venous return and stimulate the heart in accord with the Frank-Starling law.

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Skeletal System

Image removed due to copyright restrictions.
Diagram of human skeletal system.

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Skeletal structure

Axial skeleton -skull, vertebral column and ribs

Appendicular skeleton - pectoral girdle, pelvic girdle bones of arms, legs hands and feet

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See Figure 47.17 in [Purves].

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Skeletal system

- Consists of 206 bones large enough to count
- Five functions
  - Protection
  - Support
  - Movement
  - Mineral storage
  - Blood cell formation

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Bone

- Extracellular matrix material that contains crystals of insoluble calcium phosphate which give bone its rigidity and hardness as well as collagen fibers.
- Skeleton serves as a reservoir of calcium for the rest of the body and is in dynamic equilibrium with soluble calcium in the extracellular fluids of the body.

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Living cells of the bone

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See Figure 47.13 in [Purves].

- Osteoblasts -lay down the new matrix material on bone surfaces
- Osteocytes -are osteoblasts that become trapped in the matrix. Theses cells remain in contact with one another through long cellular extensions that run through channels on the bone
- Osteoclasts-cells that reabsorb the bone. These cells erode bone, forming cavities and tunnels (which the osteoblasts then come into and law down new matrix material)

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Bones that have common joint can work as a lever

Flexor and extensor muscles work antagonistically to operate the joint

Tendons attache muscle to bone

Ligaments attach bone to bone

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See Figure 47.16 in [Purves].

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Types of joints

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See Figure 47.17 in [Purves].

1. Shoulders and hips - allow movement in almost any direction
2. Two bones of the forearm meet - allows the smaller bone to rotate when the wrist is twisted from side to side
3. In hand -permit movement in two different planes (base of the thumb)
4. In finger Metacarpal - some rotation possible (this is also called Condyloid joint)
5. Knee joint - no rotational movement and can flex in one direction only
6. Ankle -allows rotational movement in only one plane

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Bones as Levers

- Bones can be thought of as system of levers that are moved around joints by the muscles
- Lever has a power arm and a load arm that work around a fulcrum (pivot)
- The length ratio of the two arms determines whether a particular lever can exert a lot of force over a short distance or is better at translating force into large or fast movement

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Bones and joints as levers

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See Figure 47.18 in [Purves].

A. Lever system designed for power - load arm:power arm = 2:1 ratio which generates much force over a small distance (ie human jaw)
B. Lever system designed for speed - load arm: power arm= 5:1 ratio which moves low weights long distances with speed (ie human leg)

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Summary

- Reviewed the basic chemistry, anatomy and physiology needed to start to manipulate the experimental device (ie. Our bodies) to begin to understand how we can improve our functioning state!

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