Biosignals and Systems

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Physiological and anatomical background

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Importance of human anatomy and physiology for BME

- BME is an interdisciplinary field based in both
  - engineering and
  - life sciences
- Important that biomedical engineers
  - have knowledge about both areas
  - are able to communicate in both areas
- Basic components of the body must be understood and how they function to
  - understand l imitations of engineering with respect to human body
  - exchange ideas with medical professionals
  - develop new ideas

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- Anatomy
  - internal and external structures of the body and their physical relationships
- Physiology
  - functions of those structures
- Medical terminology

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Anatomical positions

- superior - inferior
  - superior vena cava is in the chest, inferior vena cava is in the abdomen
- distal – proximal
  - upper arm is proximal to the elbow, lower arm is distal to the elbow
- medial – lateral
  - nose is medial to the eyes; ears are lateral to the eyes
- central – peripheral
  - central nervous system is located along the main axis of the body;
  - peripheral nervous system is outside the central nervous system
- anterior (ventral) - posterior (dorsal)
  - trachea is anterior to the esophagus, while esophagus is posterior to the trachea

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Anatomical positions

- superficial – deep
  - Superficial blood vessels are closer to the skin than those that lie deep in the abdominal cavity.
- afferent – efferent
  - la neuron is afferent leading to the spinal cord but motoneuron is efferent because it leads to the muscle
- descending – ascending
  - ascending and descending aorta
- internal – external
  - intra- and extra cellular space is divided by cell membrane
- dexter – sinister
  - heart is usually located on the left side of the thorax
- ipsilateral – contralateral
  - rm and leg can be ipsilateral (on the same side) but legs and contralateral (on opposite side)

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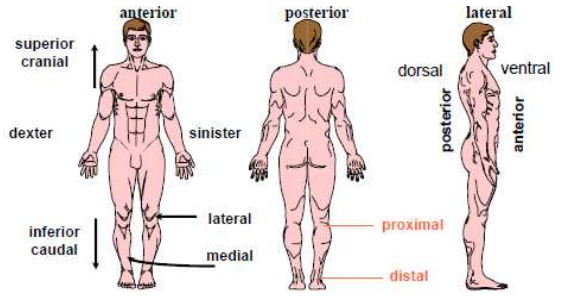

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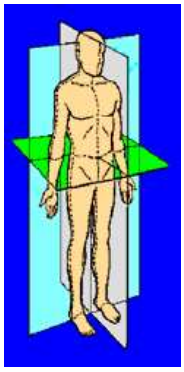
- plane projections
  - frontal (coronal)
    - front and back parts
  - sagittal
    - left and right parts
  - transverse (horizontal)
    - superior and inferior



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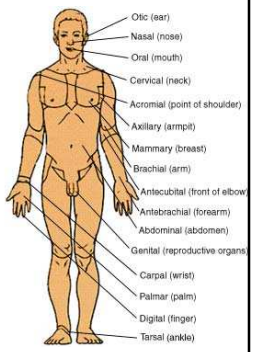
Body regions

- Axial
  - head, neck, chest, abdomen, pelvis
- appendicular (=limbs)
  - upper and lower extremities



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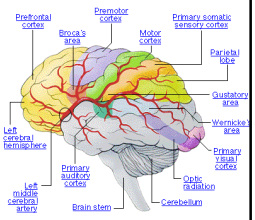
- head
  - cephalic = head
  - cranial = skull
  - frontal = forehead
  - occipital = back of the head
  - temporal = on the temple
  - parietal = on the crown
  - oral = mouth
  - nasal = nose



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- Thorax
  - Pectoral = chest
  - Mammary = breast
  - Axillary = armpit
  - Vertebral = backbone
  - Costal = ribs
- Abdomen
  - Celiac = abdomen
  - Pelvic = lower portion of abdomen
  - Gluteal = buttock
  - Inguinal = groin
  - Groin = depressed region of abdomen near thigh
  - Lumbar = lower back
  - Sacral = where vertebrae terminate

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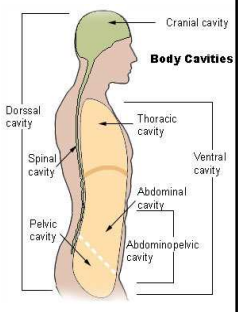
Body cavities

- hold the internal organs
- dorsal cavity
  - cranial (brain)
  - spinal (spinal cord)
- ventral cavity
  - thoracic:
    - lung, heart, trachea, esophagus
  - Abdomic
    - stomach, intestines, liver, spleen, pancreas, kidneys, gall bladder
  - Pelvic
    - urinary bladder, rectum



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Body organizations

- Atom
  - submicroscopic
- Molecule
  - formed by a group of atoms
- Cellular or Organelle
  - tiny membranous structures that perform cell functions
- Tissue
  - composed of similar types of cells and performs a specific function
- Organ
  - composed of several types of tissues and performs a particular function
- Organ system
  - group of related organs working together
- Organism
  - a living thing

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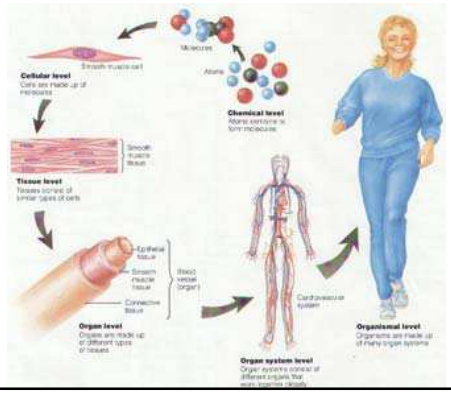

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Cellular organization

- Cells
- smallest anatomical and physiological unit in the human body
- composed of
  - organic compounds
    - carbohydrates, lipids, proteins, nucleic acids
    - work as energy packet, storehouses of energy and hereditary information, structural materials, metabolic workers
  - water (60 % of the weight)
  - most common elements: **O, C, H, N, Ca, F, K, Na, Cl, Mg**

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Cells, compounds

- carbohydrates
  - Function:
    - structural material,
    - transport,
    - energy storage
  - Types:
    - Monosaccharides (glugose)
    - Oligosaccharides (lactose, maltose)
    - Polysaccharides (glycogen)

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- lipids
  - Greasy or oily compounds that dissolve in each other but not in water
  - Function:
    - structural materials in cells
    - main reservoirs of stored energy

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- proteins
  - Most diverse form of biological molecules, built from a small number (20) of essential amino acids
  - Enzymes (specialized proteins):
    - Make metabolic reactions proceed at a faster rate
    - Enable cells to produce the organic compounds of life
  - Structural elements in a body
    - Act as transport channels across cell membranes
    - Function as signals for changing activities
    - Provide chemical weapons against disease-carrying bacteria

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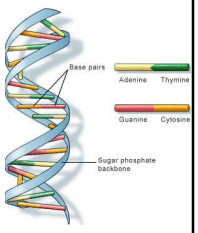
Nucleotides and nucleic acids

- Nucleotides: small organic compounds that contain
  - a five-carbon sugar (ribose or deoxyribose)
  - a phosphate group, ATP (adenosine triphosphate) =ENERGY of the cells
  - Nitrogen-containing base
- Nucleic acids
  - DNA, deoxyribonucleic acid
    - Helical molecule that contains chains of paired nucleotides that run in opposite directions
  - RNA, ribonucleic acid
  - Contain
    - Pyrimidine bases: thymine (T) or cytosine (C)
    - Purine bases: adenine (A) or guanine (G)



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Cellular organization

- Cells
  - Cells are surrounded by plasma membrane that separates (not isolate) cell´s interior from its environment
- Plasma membrane
  - Gives mechanical strength
  - Provides structure
  - Helps with movement
  - Controls the cell´s volume
  - Controls cell´s activities by regulating the movement of chemicals in and out of the cell

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- Plasma membrane is composed of:
  - Two layers of phospholipids (fat) interspersed with protein and cholesterol
- Proteins are:
  - binding sites for hormones,
  - recognition markers for identifying cells
  - adhesive mechanisms for binding adjacent cells to each other
  - channels for transporting materials across plasma membrane

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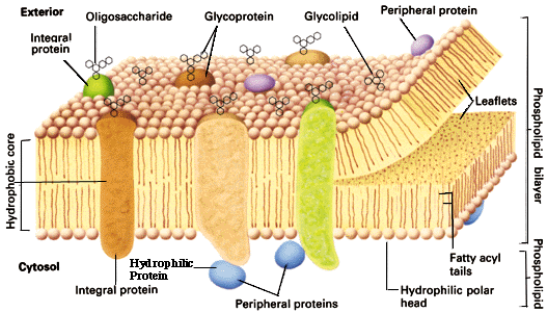

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Plasma membrane

- Permeability, P [m/s] $P=D/h$
  - D = diffusion coefficient
  - h = thickness of the membrane
- Some molecules can easily cross the plasma membrane:
  - gases: oxygen, carbon dioxide
  - small uncharged polar molecules: urea, water
- Other substances must move through the protein channels
  - large molecules and ions

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Plasma membrane

- Permeability
  - transport mechanisms:
    - passive transport
      - movement of dissolved matter toward thermodynamical equilibrium (along the electrochemical gradient)
        - direct diffusion through the lipid
        - electro diffusion through the protein channels
        - facilitated diffusion through channels (carrier mediated)
    - active transport
      - consumes energy
      - as a result of the active transport, an equilibrium is achieved that differs from the thermo-dynamical equilibrium
      - can occur against the electrochemical gradient

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Plasma membrane

- Permeability
  - Osmosis
    - Process by which substances move across a selectively permeable membrane (=plasma membrane)
  - Diffusion:
    - Movement of molecules from an area of relatively high concentration to an area of low concentration (⇒ diffusion equilibrium)
      - C = concentration
      - D = diff. coefficient
      - f = friction

$J_D = D(\Delta C/\Delta x)$, $D = kT/f$

  - Active transport
    - Requires energy (ATP) to move ions across the membrane usually from low to high concentration area
    - Na-K pump
    - Generate ion gradients across the membrane
      - For transport processes and to generate electric signals

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Plasma membrane

- Role to regulate cell volume
  - By controlling the internal osmolarity of the cell
  - Osmolarity = concentration of dissolved substances
    - 1 Osm =1 mol of dissolved particles in liter of a solution
    - high osmolarity = low water concentration

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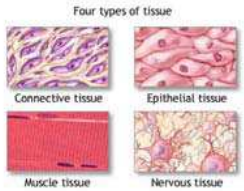
Tissues

- Tissues:
  - Groups of cells and surrounding substances that function together to perform one or more specialized activities
- Tissue types:
  - Epithelial
  - Connective
  - Muscle
  - Nervous



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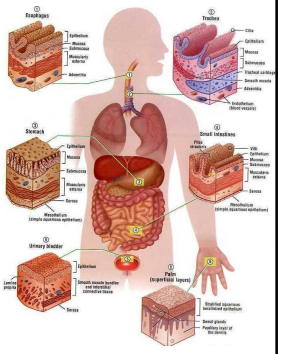
Epithelial tissue

- absorption (small intestine),
- secretion (glands),
- transport (kidney tubulus)
- excretion (sweat glands),
- protection (skin),
- sensory reception (taste buds)



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Connective tissue

- Most abundant and widely distributed
- Loose (woven fibers around and between tissues)
- Irregularly dense (protective capsules around organs)
- Regularly dense (ligament and tendons)
- Specialized connective tissues
  - Blood
  - Bone
  - cartilage

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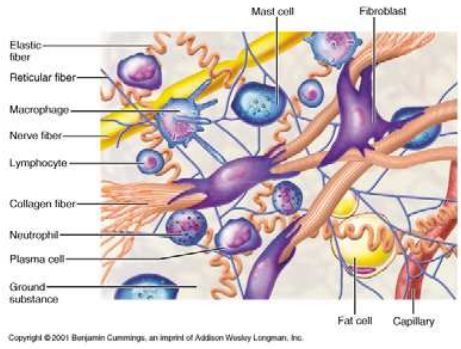

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Muscle tissue

- Provide movement for the body
- Specialized cells that can shorten in response to stimulation and then return to their un-contracted state
- Types:
  - Skeletal (attached to bones)
  - Smooth (in the walls of vessels)
  - Cardiac (only in the heart)

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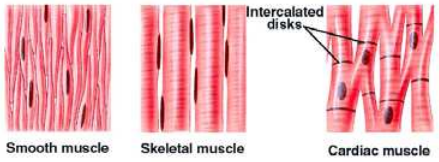
Types of Muscle



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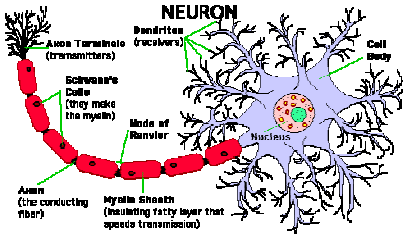
Nervous tissue

- Consists
  - neurons that conduct electrical impulses
  - Glial cells that protect, support and nourish neurons



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Major organ systems

- Organs:
  - Combinations of tissues that perform complex tasks
- Organ systems
  - Organs that function together
  - 11 organ systems
    - Integumentary, endocrine, lymphatic, digestive, urinary, reproductive, circulatory, nervous, respiratory, skeletal, muscular

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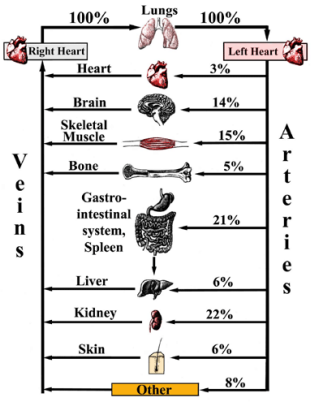

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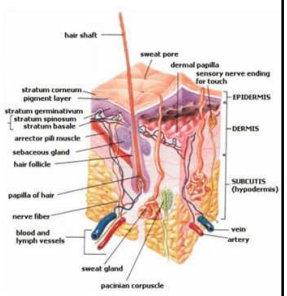
Integumentary

- Functions
  - provides body covering,
  - protection,
  - synthesis of vitamin D,
  - site of cutaneous receptors
  - and sweat glands
- comprises of
  - Skin
  - Hair
  - Nails
  - various glands



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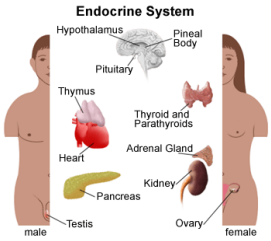
Endocrine

- Functions
  - secretes hormones that regulate many chemical actions within cells (growth, reproduction, metabolism)
- comprises of
  - ductless glands
  - Thyroid
  - Pancreas
  - Adrenals
  - ovary, testes
  - thymus, thyroid
  - Pituitary
  - pineal



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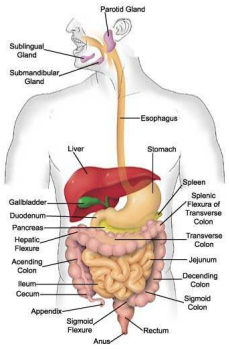
Digestive

- Functions
  - ingest food and water
  - breaks food down into small molecules which can be absorbed and used by cells
  - removes solid wastes
- comprises of
  - oral cavity
  - Esophagus
  - Stomach
  - Liver
  - Intestines
  - other structures



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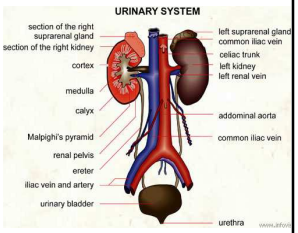
Urinary

- Functions
  - maintains the fluid volume of the body
  - eliminates metabolic wastes
  - helps regulate blood pressure
  - regulates acid-base and water-salt balances
- comprises of
  - Kidneys
  - ureters
  - urinary bladder
  - urethra



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Reproductive

- Functions
  - produces eggs or sperm
  - provides a mechanism for the production and nourishment
- comprises of
  - ovaries
  - testes
  - reproductive cells
  - accessory glands and ducts
  - mammary gland

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Circulatory

- Functions
  - serves as distribution system of various substances and solutions for the body
    - nutrients, hormones, oxygen
  - removes waste products
    - carbon dioxide
  - provides mechanism for regulating temperature and removing the heat generated by the metabolic activities of the body´s internal organs

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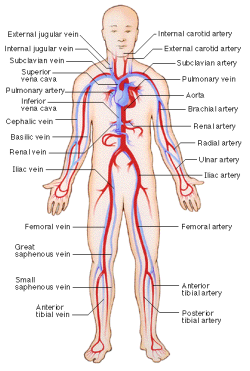
Circulatory

- comprises of
  - heart
  - blood
  - blood vessels
- divided to
  - arteries/veins
  - systemic/pulmonary



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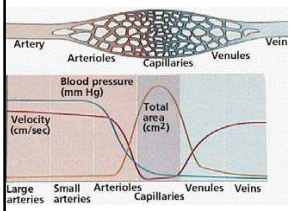
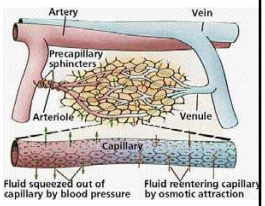
Circulatory

arteries capillaries veins





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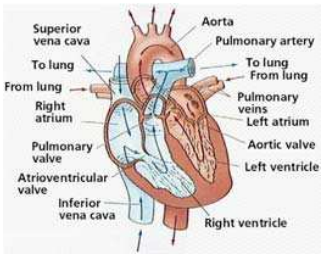
Circulatory

- heart
  - two sides
    - lungs→left→body
    - body→right→lungs
  - Chambers
    - vein→
      - atrium→
      - ventricle→
      - artery



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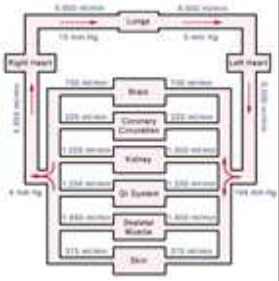
Circulatory

- blood
  - volume 5 liters
    - 75% in systemic
    - 20% in pulmonary
    - 5 % in capillaries
  - cardiac output 5-20 l/min
    - stroke volume 80 ml
    - heart beat 60-200 bpm



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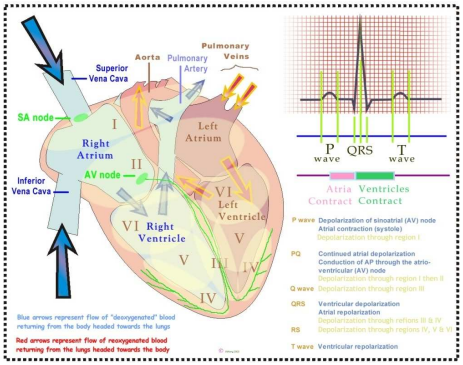
cardiac cycle



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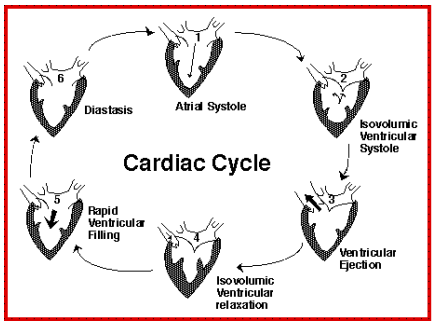
cardiac cycle



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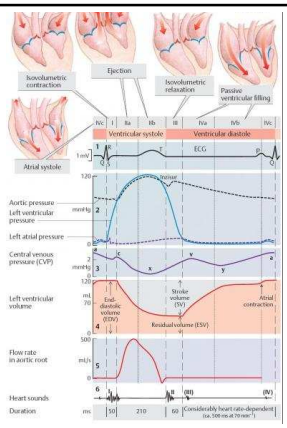
- cardiac cycle
  - Systole
  - Diastole
  - pressure
  - volume
  - flow



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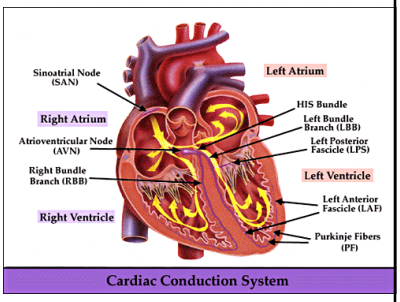
cardiac cycle

- Electrical activation
- conduction system



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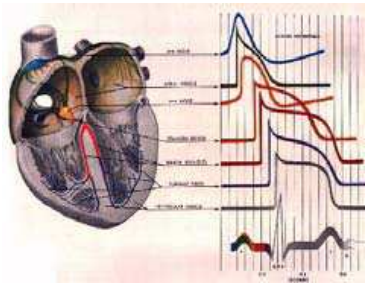
cardiac cycle

- activation sequence
- ECG



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Circulatory

- role of BME
  - electric activity
    - electrophysiology, electrocardiology
    - cardiac pacemaker, defibrillator
  - pumping function
    - assisting devices, artificial valves
  - Hemodynamics
    - pressure, flow: measurement, modelling
  - coronary arteries, ischemia
    - imaging: angiography
    - by-pass, stents

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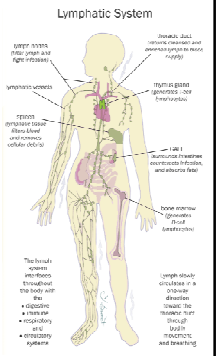
Lymphatic/Immunity

- Functions
  - returns excess fluid and protein to the blood
  - part of immune system: helps defend the body against infection and tissue damage
- comprises of
  - Glands
  - lymph nodes
  - Lymph
  - lymphatic vessels
  - spleen
  - bone marrow



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Respiratory

- functions
  - delivers oxygen to the blood from the air
  - carries carbon dioxide away
- comprises of
  - airways
  - upper airways
    - nasal cavity
    - Mouth
    - pharynx, larynx
  - lower airways
    - trachea
    - bronchi
  - lungs
    - alveoli

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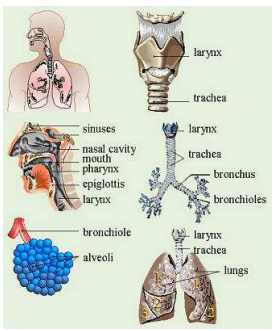
Respiratory

- physical properties
  - compliance
    - expansion
  - elasticity
    - return to original sizes after distended
  - surface tension
    - resist distension
  - flow resistance



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Respiratory

- breathing (ventilation)
  - mechanical process composed of:
    - inspiration (active)
      - inspiratory muscles contract ⇒
      - thoracic cavity enlarges ⇒
      - alveoli enlarge ⇒
      - alveolar gas espands ⇒
      - pressure within lungs drops below atm. pressure ⇒
      - air flows in (Boyle´s law)
    - expiration (passive)
      - inspiratory muscles relax ⇒
      - thoracic cavity returns to its original volume
  - normal frequency: 15-20 breaths per minute

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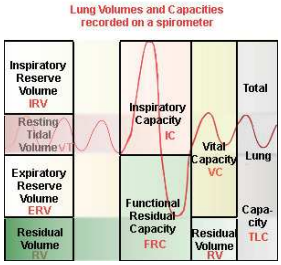
Respiratory

- lung mechanism
  - study of mechanical properties of the lung and chest wall
  - lung volumes
  - lung capacities
  - spirometer
    - volume changes
    - flow rate
    - pressures



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Respiratory

- gas exchange
  - between blood and alveoli
  - direction and rate of movement of gas depends on
    - partial pressure gradient ⇒diffusion
    - surface are of alveoli:
      - about 3.5×108 alveoli =60-70 m2 for gas exchange
    - thickness of membrane that the gas must pass trough
    - diffusion constant (∝ solubility and molecular weight of gas (Fick´s law)

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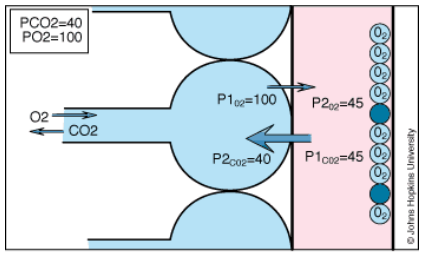
Respiratory



Alveolar-Capillary Interface

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Nervous

- Functions
  - regulates most of the body activities detecting and responding to internal and external stimuli
  - higher (intelligent) function
- comprises of
  - central nervous system
    - brain, spinal cord
  - peripheral nervous system
    - somatosensory and motor nerves
  - somatic and autonomic sensory system
  - sensory organs

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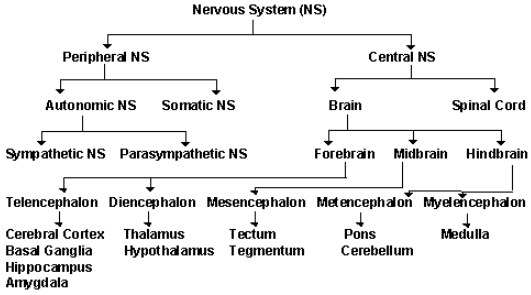
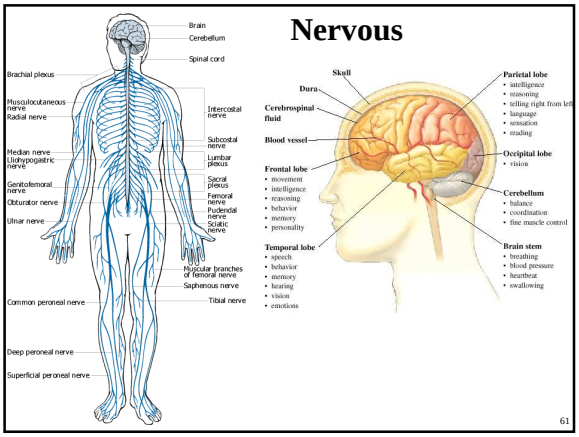
Nervous



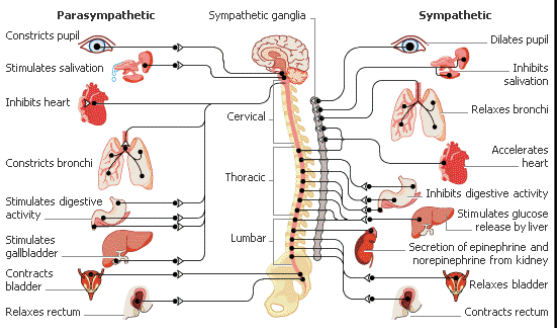
60

Nervous



61

Nervous



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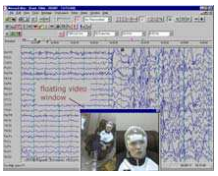
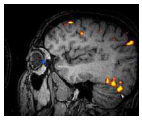
Nervous

- role of BME
  - electroencephahography , EEG
  - imaging
  - neuroprostheses
  - neurostimulators





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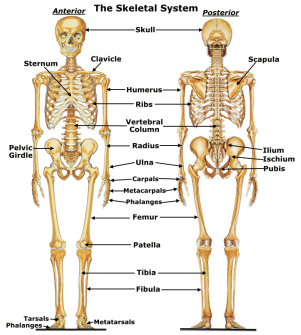
Skeletal

- functions
  - provides protection and support
  - provides as sites for muscle attachments
  - production of blood cells, calcium and phosphorus storage
- comprises of
  - bones
  - cartilage



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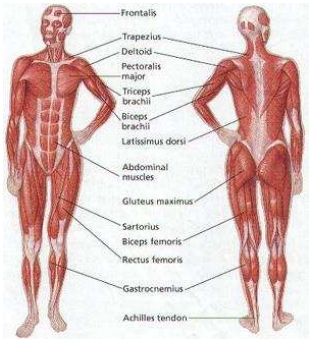
Muscular

- functions
  - moves the body ant its internal parts
  - maintains posture
  - produces heat
- comprises of
  - skeletal muscles
  - 600-700 muscles
  - smooth muscles
  - heart muscle



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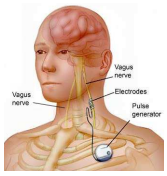
Muscular

- role of BME
  - functional nerve stimulator
  - muscle stimulators
  - force and gait analysis



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