Chapter 20
Cardiovascular System
The Heart

Functions of the Heart

- **Generating** blood pressure
- **Routing** blood: separates pulmonary and systemic circulations
- **Ensuring** one-way blood flow: valves
- **Regulating** blood supply
  - Changes in contraction rate and force match blood delivery to changing metabolic needs
Size, Shape, Location of the Heart

- **Size of a closed fist**
- **Shape**
  - **Apex**: Blunt rounded point of cone
  - **Base**: Flat part at opposite of end of cone (Superior)
- **Located in thoracic cavity in mediastinum** (central core of the thoracic cavity)

Pericardium

- **Pericardium** or pericardial sac
- **Fibrous pericardium**: tough fibrous outer layer. Prevents over distention; acts as anchor
- **Serous pericardium**: thin, transparent, inner layer. Simple squamous epithelium
  - **Parietal pericardium**: lines the fibrous
  - **Visceral pericardium** (epicardium): covers heart surface
  - The two are continuous and have a pericardial cavity between them filled with pericardial fluid
**Heart Wall**

- **Three layers of tissue**
  - **Epicardium**: Serous membrane; smooth outer surface of heart
  - **Myocardium**: Middle layer composed of cardiac muscle cell and responsibility for heart contracting
  - **Endocardium**: Smooth inner surface of heart chambers

- **(Musculi pectinati**: muscular ridges in auricles and right atrial wall)

- **(Trabeculae carnae**: muscular ridges and columns on inside walls of ventricles)

**External Anatomy**
Coronary Circulation: Veins

- **Great cardiac vein** and small cardiac vein drain right margin of heart
- **Coronary sinus**: veins empty here then into the right atrium
- Number of small veins drain the rest of the heart

Heart Chambers

- **Atria**
  - **Right atrium**: three major openings to receive blood returning from the body (superior vena cava, inferior vena cava, coronary sinus)
  - **Left atrium**: four openings that receive blood from pulmonary veins
  - **Interatrial septum**: wall between the atria. Contains a depression, the foramen ovale, a remnant of the fetal opening between the atria
- **Ventricles**
  - **(Atrioventricular canals**: openings between atria and respective ventricles )
  - **Right ventricle** opens to pulmonary trunk
  - **Left ventricle** opens to aorta
  - **Interventricular septum** between the two.
Structure of the Heart Valves

- **Atrioventricular valves** (AV valves). Each valve has leaf-like cusps that are attached to cone-shaped papillary muscles by tendons (chordae tendineae). Right has three cusps (tricuspid). Left has two cusps (bicuspid, mitral).
- **SOUND= LUBB**
- **Semilunar valves**. Right (pulmonary); left (atrial). Each cusp is shaped like a cup. When cusps are filled, valve is closed; when cusps are empty, valve is open.
- **SOUND= dupp**

Blood Flow Through Heart
(Heart Skeleton)

- Consists of plate of fibrous connective tissue between atria and ventricles
- Fibrous rings around valves to support
- Serves as electrical insulation between atria and ventricles
- Provides site for muscle attachment

Cardiac Muscle

- Elongated, branching cells containing 1-2 centrally located nuclei
- Contains actin and myosin myofilaments
- **Intercalated disks**: specialized cell-cell contacts.
  - Cell membranes interdigitate
  - Desmosomes hold cells together
  - Gap junctions allow action potentials to move from one cell to the next.
- Electrically, cardiac muscle of the atria and of the ventricles behaves as a single unit
Conducting System of Heart

Action Potentials in Skeletal and Cardiac Muscle
Autorhythmicity: SA Node Action Potential

- **Prepotential**: spontaneously developing local potential. Results in generation of action potentials in the SA node.

Electrocardiogram

- **Record of electrical event in the myocardium that can be correlated with mechanical events**
- **P wave**: depolarization of atrial myocardium. Signals onset of atrial contraction
- **QRS complex**: ventricular depolarization and signals onset of ventricular contraction. Repolarization of atria simultaneously.
- **T wave**: repolarization of ventricles; precedes ventricular relaxation
- **PQ interval** or **PR interval**: 0.16 sec; atria contract and begin to relax, ventricles begin to contract
- **QT interval**: 0.36 sec; ventricles contract and begin to relax
Cardiac Cycle

• Heart is two pumps that work together, right and left half
• Repetitive contraction (systole) and relaxation (diastole) of heart chambers
• Blood moves through circulatory system from areas of higher to lower pressure.
  – Contraction of heart produces the pressure

Cardiac Cycle. Systole: Period of isovolumic contraction

• Begins at the completion of the QRS complex.
• Ventricular muscles start to contract, increasing the pressure inside the ventricles. This causes the AV valves to close, which is the beginning of ventricular systole. The semilunar valves were closed in the previous diastole and remain closed during this event.
• 120-130 mL of blood are in the ventricles, left from the last diastole when the atria emptied into the ventricles. This is referred to as the end diastolic volume.
Cardiac Cycle. Systole: Period of Ejection

- Pressure in the ventricle has increased to the point where it is greater than the pressure in the pulmonary trunk/aorta. This pushes the cusps of the semilunar valves against the walls of the vessels, opening the valve.
- Blood is ejected from the ventricles.
- The pressures in the two ventricles are different: 120 mm Hg in the left ventricle; 25 mm Hg in the right ventricle. Remember: blood in the left ventricle must be pumped to the whole body; blood in the right ventricle is pumped to the lungs.
- After the first initial spurt, pressure starts to drop.
- At the end of the period of ejection, 50-60 mL remain: end-systolic volume.

Cardiac Cycle. Diastole: Period of isovolumic relaxation

- Completion of T wave results in ventricular repolarization and relaxation.
- Ventricular pressure falls very rapidly.
- Pulmonary trunk/aorta pressure is higher than ventricular pressure.
- Elastic recoil of the arteries causes blood to flow back toward the relaxed ventricles: the semilunar valves close, which is the beginning of ventricular diastole.
- Note that the AV valves are also closed.
Cardiac Cycle. Diastole: Passive ventricular filling

- While the ventricles were in systole, the atria were filling with blood.
- Atrial pressure rises above ventricular pressure and the AV valves open.
- Blood flows into the relaxed ventricles, accounting for most of the ventricular filling (70%).

Cardiac Cycle. Diastole: Active ventricular filling

- Depolarization of the SA node generates action potentials that spread over the atria (P wave) and the atria contract. This completes ventricular filling.
- At rest, contraction of atria not necessary for heart function.
- During exercise, atrial contraction necessary for function as heart pumps 300-400%.
Mean Arterial Pressure (MAP)

- Average blood pressure in aorta
- MAP = CO x PR
  - CO is amount of blood pumped by heart per minute
    - CO = SV x HR
      - SV: Stroke volume (blood pumped during each heart beat)
      - HR: Heart rate (number of times heart beats per minute)
    - Cardiac reserve: Difference between CO at rest and maximum CO
  - PR is total resistance against which blood must be pumped
Regulation of the Heart

- **Intrinsic regulation**: Results from normal functional characteristics, not on neural or hormonal regulation
  - **Preload**: Starling’s law of the heart
    - Preload is the amount of stretch of the ventricular walls. The greater the stretch (preload), the greater the force
  
  - **Afterload**: pressure the contracting ventricles must produce to overcome the pressure in the aorta and move blood into the aorta. Heart not as sensitive to this as it is to changes in preload.
Heart Homeostasis

- **Effect of blood pressure**
  - Baroreceptors monitor blood pressure; in walls of internal carotids and aorta. This sensory information goes to centers in the medulla oblongata

- **Effect of pH, carbon dioxide, oxygen**
  - Receptors that measure pH and carbon dioxide levels found in hypothalamus
  - Chemoreceptors monitoring oxygen levels found in aorta and internal carotids. Prolonged lowered oxygen levels causes increased heart rate, which increases blood pressure and can thus deliver more oxygen to the tissues.

- **Effect of extracellular ion concentration**
  - Increase or decrease in extracellular $K^+$ decreases heart rate

- **Effect of body temperature**
  - Heart rate increases when body temperature increases, heart rate decreases when body temperature decreases

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Baroreceptor and Chemoreceptor Reflexes
Baroreceptor Reflex

Chemoreceptor Reflex-pH
Effects of Aging on the Heart

- Gradual changes in heart function, minor under resting condition, more significant during exercise
- **Hypertrophy** of left ventricle
- Maximum heart rate decreases
- Increased tendency for valves to function abnormally and arrhythmias to occur
- Increased oxygen consumption required to pump same amount of blood