Cardiovascular system = blood vessels and heart.

Functions of circulatory system.

1.  
2.  
3.  

Blood Components

- Plasma
  - Organic and inorganic substances
  - Bilirubin
  - Albumins, globulins and fibrinogen
- Erthyrocytes (RBCs)
- Leukocytes (WBCs)
- Platelets

You will not be tested on material from Hematopoiesis through Dissolution of clots (pp. 370 - 377).

- However it makes for very interesting reading.
Buffer Systems

- Provide or remove H⁺ and stabilize the pH.
- Include weak acids that can donate H⁺ and weak bases that can absorb H⁺.
- HCO₃⁻ is the most important ECF buffer.
- H⁺ + HCO₃⁻ → H₂CO₃

Acid Base Disorders

- Respiratory acidosis:
  - Accumulation of CO₂.
  - pH decreases.
- Respiratory alkalosis:
  - Excessive loss of CO₂.
  - pH increases.

Acid Base Disorders

- Metabolic acidosis:
  - Gain of fixed acid or loss of HCO₃⁻.
  - Plasma HCO₃⁻ decreases.
  - pH decreases.
- Metabolic alkalosis:
  - Loss of fixed acid or gain of HCO₃⁻.
  - Plasma HCO₃⁻ increases.
  - pH increases.

pH

- Normal pH is obtained when the ratio of HCO₃⁻ to CO₂ is 20:1.
- Henderson-Hasselbalch equation:
  \[ pH = 6.1 + \log \frac{[HCO₃^-]}{[CO₂]} \]
Cardiac Cycle

- Refers to the repeating pattern of contraction and relaxation of the heart.
- Systole:
  - Phase of contraction.
- Diastole:
  - Phase of relaxation.

ECG

Electrocardiogram (ECG)

- Step 1: Isovolumetric contraction.
- QRS just occurred.
- Contraction of the ventricle causes ventricular pressure to rise above atrial pressure.
  - AV valves close.
- Ventricular pressure is less than aortic pressure.
  - Semilunar valves are closed.
- Volume of blood in ventricle is EDV.
Cardiac Cycle

• Step 2: Ejection.
  • Contraction of the ventricle causes ventricular pressure to rise above aortic pressure.
    – Semilunar valves open.
  • Ventricular pressure is greater than atrial pressure.
    – AV valves are closed.
  • Volume of blood ejected: SV.

• Step 3: T wave occurs.
  • Ventricular pressure drops below aortic pressure.

• Step 4: Isovolumetric relaxation.
  • Back pressure causes semilunar valves to close.
    – AV valves are still closed.
  • Volume of blood in the ventricle: ESV.

• Step 5: Rapid filling of ventricles.
  • Ventricular pressure decreases below atrial pressure.
    – AV valves open.
  • Rapid ventricular filling occurs.

• Step 6: Atrial systole.
  • P wave occurs.
    – Atrial contraction.
    – Push 10-30% more blood into the ventricle.

Heart Sounds

• Closing of the AV and semilunar valves.
• Lab (first sound):
  • Produced by closing of the AV valves during isovolumetric contraction.
• Dub (second sound):
  • Produced by closing of the semilunar valves when pressure in the ventricles falls below pressure in the arteries.

Heart Murmurs

• Abnormal heart sounds produced by abnormal patterns of blood flow in the heart.
• Defective heart valves:
  – Valves become damaged by antibodies made in response to an infection.
• Mitral stenosis:
  – Mitral valve becomes thickened and calcified.
  – Impair blood flow from left atrium to left ventricle.
Heart Murmurs

- Incompetent valves:
  - Valves do not close properly.
  - Murmurs may be produced as blood regurgitates through the valve flaps.
- Septal defects:
  - Holes in septum between the left and right sides of the heart.
  - Blood passes from left to right.

Abnormal Patterns of Blood Flow Due to Septal Defects

- Septal defect in atria
- Septal defect in ventricles

Left-to-right shunting of blood is shown by circled areas.

Fig. 13.15

Blood Flow through a Patent (Open) Ductus Arteriosus

Fig. 13.16

Conducting system of heart

- Superior vena cava
- Atrioventricular node
- Bundle of His
- Sinoatrial node
- Right bundle branch
- Purkinje fibers
- Left bundle branch

Fig not in book

Electrical Activity of the Heart

- Automaticity: automatic nature of the heartbeat.
- SA node:
  - Demonstrates spontaneous depolarization.
  - Functions as the pacemaker.
  - Does not maintain a stable resting membrane potential.
  - Membrane depolarizes from –60 to –40 mV.

Pacemaker Potential

- –40 mV is threshold for producing AP.
- Spontaneous diffusion caused by diffusion of Ca++ through slow Ca++ channels.
Depolarization

- Depolarization:
  - VG fast Ca\textsuperscript{2+} channels open.
  - Ca\textsuperscript{2+} diffuses inward.
  - Opening of VG Na\textsuperscript{+} channels may also contribute to the upshoot phase of the AP.

- Repolarization:
  - VG K\textsuperscript{+} channels open.
  - K\textsuperscript{+} diffuses outward.

Cardiac Muscle AP

- Resting membrane potential of \(-90\) mV.
- SA node AP spreads to myocardial cells.
- When myocardial cell reaches threshold, the cell depolarizes.
- Rapid upshoot occurs:
  - VG Na\textsuperscript{+} channels open.
  - Inward diffusion of Na\textsuperscript{+}.

Cardiac Muscle AP

- Plateau phase:
  - Rapid reversal in membrane polarity to \(-15\) mV.
  - VG Ca\textsuperscript{2+} channels open.
  - Slow inward flow of Ca\textsuperscript{2+} balances outflow of K\textsuperscript{+}.

- Rapid repolarization:
  - VG K\textsuperscript{+} channels open.
  - Rapid outward diffusion of K\textsuperscript{+}.

Conducting Tissues of the Heart

- APs spread through myocardial cells through gap junctions.
- Impulses cannot spread to ventricles directly because of fibrous tissue.
- Conduction pathway:
  - SA node.
  - AV node.
  - Bundle of His.
  - Purkinje fibers.
Conduction of Impulse

- AP from SA node spread quickly at rate of 0.8 - 1.0 m/sec.
- Time delay occurs as impulses pass through AV node.
  - Slow conduction of 0.03 – 0.05 m/sec.
- Impulse conduction increases as spread to Purkinje fibers at a velocity of 5.0 m/sec.
- Ventricular contraction begins 0.1 – 0.2 sec. After contraction of the atria.

Cardiac excitation

Atrial excitation

Ventricular excitation

Fig not in book

Membrane potential of ventricular muscle

Relative permeability during action potential

Refractory Periods

- Heart contracts as one single unit.
- Contraction lasts almost 300 msec.
- Refractory periods last almost as long as contraction.
- Summation cannot occur.

Fig. 13.20
**EKG (ECG)**

- The body is a good conductor of electricity.
  - Due to the high concentration of ions that move in response to potential differences.
- Electrocardiogram:
  - Measure of the **electrical activity** of the heart per unit time.
  - Does **NOT measure** the flow of blood through the heart.

**EKG Leads**

- 2 types of leads:
  - Bipolar leads:
    - Record voltage between electrodes placed on wrists and legs.
    - Right leg is ground.
  - Unipolar leads:
    - Placed on right arm, left arm, left leg and chest.
    - Allow to obtain a 3 dimensional perspective of the heart.

**ECG**

![Electrocardiogram (ECG)](image1)

- P wave:
  - Atrial depolarization.
- QRS complex:
  - Ventricular depolarization.
  - Atrial repolarization.
- T wave:
  - Ventricular repolarization.

**Events during cardiac cycle**

![Events during cardiac cycle](image2)

- Heart sounds
- Aortic pressure
- Left atrial pressure
- Left ventricular pressure
- Left ventricular volume

![Typical electrocardiogram](image3)

- Membrane potential (mV)
- Ventricular action potential

![ECG Leads](image4)

- Electrocardiograph Leads
  - Right arm
  - Left arm
  - Right leg
  - Left leg
Stroke volume

- Stroke volume: volume of blood ejected by each ventricle during each contraction.
- Force contraction affected by:
  - Changes in end-diastolic volume
  - Changes in magnitude of sympathetic nervous input to the ventricles.
  - Afterload