Cardiovascular system = blood vessels and heart.

Fig. 13.9

Functions of circulatory system.

1. 
2. 
3. 

Constituents of Blood

Fig. 13.1
Blood Components

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

Formed elements

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 \( H^+ \).
- \( HCO_3^- \) is the most important ECF buffer.
- \( H^+ + HC0_3^- \rightarrow H_2C0_3 \)

Acid Base Disorders

- Respiratory acidosis:
  - Accumulation of \( CO_2 \).
  - pH decreases.
- Respiratory alkalosis:
  - Excessive loss of \( CO_2 \).
  - pH increases.

- Metabolic acidosis:
  - Gain of fixed acid or loss of \( HCO_3^- \).
  - Plasma \( HCO_3^- \) decreases.
  - pH decreases.
- Metabolic alkalosis:
  - Loss of fixed acid or gain of \( HCO_3^- \).
  - Plasma \( HCO_3^- \) increases.
  - pH increases.
pH

- Normal pH is obtained when the ratio of HCO$_3^-$ to CO$_2$ is 20:1.
- Henderson-Hasselbalch equation:
  \[ \text{pH} = 6.1 + \log \frac{[\text{HCO}_3^-]}{[\text{CO}_2]} \]
Cardiac Cycle

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

Fig. 13.10
ECG

See Fig. 13.21

Cardiac Cycle

- 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.

Cardiac Cycle

- **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.

Cardiac Cycle

- **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.
- \(\text{Lub} \) (first sound):
  - Produced by closing of the AV valves during isovolumetric contraction.
- \(\text{Dub} \) (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.

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**Abnormal Patterns of Blood Flow Due to Septal Defects**

![Diagram showing abnormal blood flow due to septal defects](Fig. 13.15)

- [Diagram](Fig. 13.15)

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**Blood Flow through a Patent (Open) Ductus Arteriosus**

![Diagram showing blood flow through the ductus arteriosus](Fig. 13.16)

Fig. 13.16
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\(^{++}\) channels open.
  - Ca\(^{++}\) diffuses inward.
  - Opening of VG Na\(^{+}\) channels may also contribute to the upshoot phase of the AP.

- Repolarization:
  - VG K\(^{+}\) channels open.
  - K\(^{+}\) diffuses outward.

---

Pacemaker and Action Potentials in the SA Node

![Diagram of Pacemaker and Action Potentials in the SA Node]

**Fig. 13.17**

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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\(^{+}\) channels open.
  - Inward diffusion of Na\(^{+}\).
Cardiac Muscle AP

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

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**Action Potential in a Myocardial Cell from the Ventricles**

Fig. 13.18

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**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 System of the Heart**

Fig. 13.19
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
- Begins
- Complete

Ventricular excitation
- Begins
- Complete

Fig not in book

Membrane potential of ventricular muscle

Figure not in book
Refractory Periods

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

Figure 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.
  - The 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.

Fig. 13.22

EKG

Fig. 13.21
ECG

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

**Fig. 13.23**

**Typical electrocardiogram**

**Fig. 13.21**

Events during cardiac cycle

**Fig. not in book:**
See fig. 13.24 in book.
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

Effects on stroke volume

Figure not in book