Chapter 23: The Respiratory System

Chapter Objectives

PULMONARY VENTILATION
1. Define the three basic processes of respiration: pulmonary ventilation, external respiration, and internal respiration.
2. State Boyle’s law.
3. Discuss how Boyle’s law works through the action of the diaphragm and external intercostal muscles in the production of pressure gradients that move air into the lungs during inhalation.
4. List the accessory muscles that aid in forced inhalations.
5. Describe elastic recoil.
6. List the accessory muscles that aid in forced exhalations.
7. List the factors that control airway diameter and consequent air flow resistance.

EXCHANGE OF OXYGEN AND CARBON DIOXIDE
8. Define partial pressure of a gas and how they affect gas exchange.
10. Describe the cell and fluid compartments through which oxygen and carbon dioxide must diffuse to get from alveolar air to the tissue cells and out of the body.

TRANSPORT OF OXYGEN AND CARBON DIOXIDE IN THE BLOOD
11. Discuss the methods for transporting oxygen in blood.
12. Discuss the effect of oxygen partial pressure on oxygen binding to and dissociating from hemoglobin.
13. Discuss factors other than the partial pressure of oxygen that influence the affinity with which hemoglobin binds oxygen.
14. Explain why it is necessary for fetal hemoglobin to have a greater affinity for oxygen than maternal hemoglobin.
15. Describe the three main forms by which carbon dioxide is transported in blood.
16. Explain how these forms change in the lungs versus the tissues.
CONTROL OF RESPIRATION

17. Identify the three brain stem centers that regulate respiration.
18. Discuss the mechanism by which the medullary rhythmicity center establishes the basic cycle of ventilation.
19. Discuss the interactions between the pneumotaxic area and the rhythmicity center to initiate expiration and set the rate of breathing.
20. Describe how the apneustic area interacts with the rhythmicity center to control the transition from inspiration to expiration.
21. Explain the influences from higher CNS areas and peripheral receptors on breathing.
22. Discuss the negative feedback control system through which differing chemical conditions in the blood regulate the breathing pattern.

Chapter Lecture Notes

Introduction

The respiratory system provides for gas exchange.

Respiration is the exchange of gases between the atmosphere, blood, and cells.

three basic steps

ventilation (breathing)

external (pulmonary) respiration

internal (tissue) respiration

Pulmonary Ventilation

Inspiration (inhalation) is the process of bringing air into the lungs

The movement of air into and out of the lungs depends on pressure changes governed in part by Boyle’s law.
Boyle’s law - the volume of a gas varies inversely with pressure, assuming that temperature is constant (Fig 23.12)

Inhalation occurs when alveolar (intrapulmonic) pressure falls below atmospheric pressure. (Fig 23.13 & 23.14)

Contraction of the diaphragm, the main inspiratory muscle, and external intercostal muscles increases the size of the thoracic cavity.

The intrapleural (intrathoracic) pressure decreases so that the lungs expand.

Expansion of the lungs decreases alveolar pressure so that air moves along the pressure gradient from the atmosphere into the lungs.

During forced inhalation, accessory muscles of inspiration (sternocleidomastoids, scalenes, and pectoralis minor) are also used.

Expiration (exhalation) is the movement of air out of the lungs.

Exhalation occurs when alveolar pressure is higher than atmospheric pressure. (Fig 23.15)

Relaxation of the diaphragm and external intercostal muscles results in

ELASTIC RECOIL of the chest wall and lungs.

There is also an inward pull of surface tension due to the film of alveolar fluid.

Intrapleural pressure increases, lung volume decreases, and alveolar pressure increases so that air moves from the lungs to the atmosphere.

Exhalation becomes active during labored breathing and when air movement out of the lungs is impeded.

Forced expiration employs contraction of the internal intercostal and abdominal muscles.
Air Flow Resistance

Resistance to airflow depends upon airway size

- increase size of chest
  - airways increase in diameter – decrease resistance
- contract smooth muscles in airways
  - decreases in diameter – increase resistance

Exchange of Oxygen and Carbon Dioxide

The partial pressure of a gas is the pressure exerted by that gas in a mixture of gases. The total pressure of a mixture is calculated by simply adding all the partial pressures.

It is symbolized by \( P \).

The amounts of \( O_2 \) and \( CO_2 \) vary in inspired (atmospheric), alveolar, and expired air.

External Respiration (Fig 23.17)

\( O_2 \) and \( CO_2 \) diffuse from areas of their higher partial pressures to areas of their lower partial pressures.

Gas exchange occurs across the alveolar-capillary membrane (Fig 23.11)

Respiratory membrane = 1/2 micron thick

4 Layers of membrane to cross

- alveolar epithelial wall of type I cells
- alveolar epithelial basement membrane
- capillary basement membrane
- endothelial cells of capillary

Rate of diffusion depends on

Partial pressure differences
Large surface area of our alveoli

Diffusion distance (membrane thickness) is very small

Solubility & molecular weight of gases

O₂ is a smaller molecule and diffuses somewhat faster

CO₂ dissolves 24X more easily in water so net outward diffusion of CO₂ is much faster

Internal Respiration (Fig 23.17)

Exchange of gases between blood & tissues

Conversion of oxygenated blood into deoxygenated

Oxygen Transport

1.5% of the O₂ is dissolved in the plasma in oxygenated blood (Fig 23.18)

Only the dissolved O₂ can diffuse into tissues

98.5% is carried with hemoglobin (Hb) inside red blood cells as oxyhemoglobin (HbO₂) in oxygenated blood

P₀₂ - the most important factor that determines how much oxygen combines with hemoglobin

The greater the P₀₂, the more oxygen will combine with hemoglobin, until the available hemoglobin molecules are saturated.

Factors that promote dissociation (release) of O₂ from hemoglobin

Acidic environment (low pH) (Fig 23.20)

High P₀₂ results in low blood pH

CO₂ converts to carbonic acid & becomes H⁺ and bicarbonate ions & lowers pH.

O₂ left behind in needy tissues
Increased temperature, within limits (Fig 23.21)

Increased BPG (2, 3-biphosphoglycerate) levels

BPG is formed in red blood cells during glycolysis.

Fetal hemoglobin has greater affinity for O₂ (binds more than adult at same P₀₂) (Fig 23.22)

Differs from adult in structure

When P₀₂ is low, can carry more O₂

Maternal blood in placenta has less O₂

Carbon Dioxide Transport

Dissolved CO₂ - 7% (Fig 23.18)

Carbaminohemoglobin - 23%

Bicarbonate ions - 70%

In red blood cells, CO₂ + H₂O are combined by an enzyme, carbonic anhydrase, to form carbonic acid (Fig 23.23)

Carbonic acid will dissociate into H⁺ and bicarbonate ion

Respiratory Center

Respiratory muscles are controlled by neurons in pons & medulla (reticular formation)

3 groups of neurons (Fig 23.24)

- medullary rhythmicity (dorsal and ventral respiratory groups)

- Pneumotaxic (Pontine respiratory group)

- apneustic centers (Pontine respiratory group)

The function of the medullary rhythmicity area is to control the basic rhythm of respiration.
The inspiratory area - sets the basic rhythm of respiration (Fig 23.25)

intrinsic excitability of autorhythmic neurons

The expiratory area - used in forced (labored) expiration

eurons remain inactive during most quiet respiration

probably activated during high levels of ventilation to cause contraction of

muscles

The pneumotaxic area - helps coordinate the transition between inspiration and expiration

The apneustic area - activates inspiratory area and prolongs inspiration and inhibits

expiration

Regulation of Respiratory Center

Cerebral Cortical Influences

Voluntarily alter breathing patterns

Cortical influences allow conscious control of respiration that may be needed to avoid

inhaling noxious gasses or water.

Chemical Influences (Fig 23.26 - 23.27 & Table 23.2)

Monitored by chemoreceptors in the

carotid arteries

arch of aorta

Activates inspiratory area

increased $P_{CO_2}$

increased $H^+$

Severe deficiency of $P_{O_2}$

Result: hyperventilation, rapid and deep breathing
Inspiratory area sets its own pace

decreased arterial $P_{CO_2}$ - hypocapnia

the inspiratory center is not stimulated until $CO_2$ accumulates