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The Respiratory System

PowerPoint® Lecture Outlines
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Respiratory System Functions

Functions of Respiratory System

• Gas exchange between blood and air
• Move air to and from exchange surfaces
• Protect exchange surfaces from environmental variations and pathogens
• Produce sound
• Detect olfactory stimuli
Respiratory System Organization

Components of the Respiratory System

• Nose, nasal cavity, and paranasal sinuses
• Pharynx
• Larynx
• Trachea, bronchi
• Lungs
  • Bronchioles
  • Alveoli (gas exchange)
The Components of the Respiratory System

Figure 15-1

- Nasal cavity
- Sphenoidal sinus
- Internal nares
- Pharynx
- Frontal sinus
- Nasal conchae
- Nose
- Tongue
- Hyoid bone
- Larynx
- Trachea
- Bronchus
- Bronchioles
- Diaphragm
- Vein
- Artery
- Alveolus
- Capillary network
The Respiratory Tract

- Conducting portion
  - Conduct the air movement
  - From nares to small bronchioles

- Respiratory portion
  - Gas exchange region
  - Respiratory bronchioles and *alveoli*
Respiratory System Organization

The Nose

- External *nares* (nostrils) admit air
  - *Nasal vestibule* lined with hairs to filter air
- Vestibule opens into *nasal cavity*
  - Hard palate separates nasal and oral cavities
- Cavity continues through *internal nares* to *nasopharynx*
  - Soft palate underlies nasopharynx
- *Respiratory epithelium* lines the airways
Respiratory System Organization

The Nose, Nasal Cavity, and Pharynx

Figure 15-2
Respiratory Mucosa

- Respiratory epithelium plus supporting connective tissue with mucous glands
  - Lines nasal cavity and most of airways
  - Goblet and gland cells secrete mucus
  - Mucus traps inhaled dirt, pathogens, etc.
  - Ciliated cells sweep the mucus out of the airways into pharynx
- Irritants stimulate secretion
  - Causes “runny nose”
The Respiratory Epithelium

- Movement of mucus to pharynx
- Ciliated columnar epithelial cell
- Goblet cell
- Stem cell
- Lamina propria
- Mucus layer

Figure 15-3(a)
Respiratory System Organization

The Respiratory Epithelium

Figure 15-3(b)
Three Regions of the Pharynx (Throat)

- Respiratory system only
  - Nasopharynx
- Shared with digestive system
  - Oropharynx
    - Opens into both esophagus and larynx
  - Laryngopharynx
The Larynx

- Also called, “voice box”
- Made of nine cartilages
- Air passes through *glottis*
- Covered by *epiglottis* during swallowing
  - Keeps solids, liquids out of airways
  - Made of elastic cartilage
- Supports *true vocal cords*
  - Exhaled air vibrates them to make sound
The Anatomy of the Larynx and Vocal Cords

(a) Anterior view

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Figure 15-4(a)
The Anatomy of the Larynx and Vocal Cords

- Epiglottis
- Corniculate cartilage
- Cuneiform cartilage
- False vocal cords
- Vocal cords
- Arytenoid cartilages
- Cricoid cartilage
- Tracheal cartilages

(b) Posterior view

Figure 15-4(b)
Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords

- Corniculate cartilage
- Glottis
- Cuneiform cartilage
- False vocal cord
- Vocal cord
- Epiglottis
- Root of tongue

(c)
Respiratory System Organization

The Anatomy of the Larynx and Vocal Cords

Figure 15-4(d)
The Anatomy of the Larynx and Vocal Cords

Figure 15-4(e)
The Trachea

- Also called “windpipe”
- Stiffened by C-shaped cartilage rings
- Esophagus stuck to posterior surface
  - Cartilage missing there
- Trachea distorted by balls of food as they pass down esophagus to stomach
Respiratory System Organization

The Anatomy of the Trachea

- Hyoid bone
- Larynx
- Trachea
- Tracheal cartilage
- Primary bronchi
- RIGHT LUNG
- Secondary bronchi
- LEFT LUNG
- Esophagus
- Tracheal ligament
- Trachealis muscle (smooth muscle)
- Respiratory epithelium
- Tracheal cartilage
- Mucous gland

Figure 15-5
The Bronchi

- Trachea forms two branches
  - Right and left primary bronchi
- Primary bronchi branch
  - Form secondary bronchi
    - Each ventilates a lobe
- Secondary bronchi branch
  - Form tertiary bronchi
- Tertiary bronchi branch repeatedly
  - Cartilage decreases, smooth muscle increases
The Bronchioles

- Cartilage absent
- Diameter < 1.0 mm
- *Terminal bronchioles* deliver air to a single *lobule*
- Smooth muscle in wall controlled by ANS
  - Sympathetic causes *bronchodilation*
  - Parasympathetic causes *bronchoconstriction*
- Excess bronchoconstriction is *asthma*
Respiratory System Organization

The Bronchial Tree

Figure 15-6(a)

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Respiratory System Organization

The Alveolar Ducts and Alveoli

- Gas exchange regions of lung
- *Respiratory bronchioles* lead into *alveolar ducts*
- Ducts lead into *alveolar sacs*
- Sacs are clusters of interconnected *alveoli*
  - Gives lung an open, spongy look
  - About 150 million/lung
The Lobules of the Lung

- Respiratory epithelium
- Bronchiole
- Bronchial artery (red), vein (blue), and nerve (yellow)
- Terminal bronchiole
- Respiratory bronchiole
- Elastic fibers
- Branch of pulmonary vein
- Capillary beds
- Alveolar duct
- Branch of pulmonary artery
- Smooth muscle around terminal bronchiole
- Arteriole
- Lymphatic vessel
- Alveoli
- Alveolar sac
- Interlobular septum
- Visceral pleura
- Pleural cavity
- Parietal pleura

Figure 15-6(b)
Respiratory System Organization

Alveolar Organization

- Respiratory bronchiole
- Alveolar duct
- Alveolus
- Alveolar sac
- Smooth muscle
- Elastic fibers
- Capillaries

(a) Alveolar organization

Figure 15-7(a)
Respiratory System Organization

Alveolar Organization

(b) Alveolar ducts and alveoli

Figure 15-7(b)
Anatomy of the Alveolus
Respiratory membrane
  • Simple squamous epithelium
  • Capillary endothelium
  • Shared basement membrane
  • Septal cells
    • Produce surfactant to reduce collapse
  • Alveolar macrophages
    • Engulf foreign particles
Respiratory System Organization

Alveolar Organization

- Elastic fibers
- Septal cell (secretes surfactant)
- Capillary
- Alveolar epithelial cell
- Alveolar macrophage
- Endothelial cell of capillary

(c) Alveolar structure

Figure 15-7(c)
Alveolar Organization

(d) The respiratory membrane

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Lung Gross Anatomy

• Lungs comprise five lobes
  • Separated by deep fissures
  • three lobes on right, two on left
• Apex extends above first rib
• Base rests on diaphragm
• Covered by a serous visceral pleura
• Lie with pleural cavities
  • Lined by a serous parietal pleura
Respiratory System Organization

The Gross Anatomy of the Lungs

- Superior lobe
- Middle lobe
- Inferior lobe
- Apex
- Right Lung
- Left Lung
- Superior lobe (costal surface)
- Cardiac notch
- Inferior lobe
- Base

Anterior view

Figure 15-8
Respiratory System Organization

Anatomical Relationships in the Thoracic Cavity

Figure 15-9
Respiratory Physiology

Three Integrated Processes

• *Pulmonary ventilation*—Moving air into and out of the respiratory tract; breathing

• *Gas exchange* —Diffusion between alveoli and circulating blood, and between blood and interstitial fluids

• *Gas transport*—Movement of oxygen from alveoli to cells, and carbon dioxide from cells to alveoli
Respiratory Physiology

Pulmonary Ventilation

• *Respiratory cycle*—A single breath consisting of *inspiration* (inhala
tion) and *expiration* (exhalation)

• *Respiratory rate*—Number of cycles per minute
  • Adult normal rate 12 to 18 breaths/minute
  • Child normal rate 18 to 20 breaths/minute

• *Alveolar ventilation*—Movement of air into and out of the alveoli
Key Note

The direction of air flow is determined by the relationship of atmospheric pressure and pressure inside the respiratory tract. Flow is always from higher to lower pressure.
Quiet versus Forced Breathing

• *Quiet breathing*—Diaphragm and external intercostals are involved. Expiration is *passive*.

• *Forced breathing*—Accessory muscles become active during the entire breathing cycle. Expiration is *active*.
Respiratory Physiology

Pressure and Volume Relationships in the Lungs

Figure 15-10(a)

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**AT REST**

- Pleural space
- Mediastinum
- Diaphragm

Pressure outside and inside are equal, so no movement occurs

\[ P_o = P_i \]

**INHALATION**

- Sternocleidomastoid
- Scalene muscles
- Pectoralis minor
- Serratus anterior
- External intercostal
- Diaphragm

Volume increases
Pressure inside falls, and air flows in

\[ P_o > P_i \]

**EXHALATION**

- Transversus thoracis
- Internal intercostals
- Rectus abdominis (other abdominal muscles not shown)

Volume decreases
Pressure inside rises, so air flows out

\[ P_o < P_i \]
AT REST

Pleural space
Mediastinum
Diaphragm

Pressure outside and inside are equal, so no movement occurs
\[ P_o = P_i \]
**AT REST**

- Pleural space
- Mediastinum
- Diaphragm

Pressure outside and inside are equal, so no movement occurs: \( P_o = P_i \)

**INHALATION**

- Sternocleidomastoid
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- External intercostal
- Diaphragm

Volume increases,
Pressure inside falls,
and air flows in: \( P_o > P_i \)
Pleural space
Mediastinum
Diaphragm
Pressure outside and inside are equal, so no movement occurs \( P_o = P_i \)

INHALATION

Volume increases
Pressure inside falls, and air flows in
\( P_o > P_i \)

Sternocleidomastoid
Scalene muscles
Pectoralis minor
Serratus anterior
External intercostal
Diaphragm

EXHALATION

Volume decreases
Pressure inside rises, so air flows out
\( P_o < P_i \)

Transversus thoracis
Internal intercostals
Rectus abdominis
(other abdominal muscles not shown)
Capacities and Volumes

- **Vital capacity**—Tidal volume + expiratory reserve volume + inspiratory volume
  \[ VC = TV + ERV + IRV \]
- **Residual volume**—Volume of air remaining in the lung after a forced expiration
Gas Exchange

- *External respiration*—Diffusion of gases between alveolar air and pulmonary capillary blood across the respiratory membrane

- *Internal respiration*—Diffusion of gases between blood and interstitial fluids across the capillary endothelium
Respiratory Physiology

An Overview of Respiration and Respiratory Processes

Respiration: Gas Exchange

Figure 15-12

Respiratory membrane
Alveolus

Pulmonary capillary

Interstitial fluid

Systemic circuit

Pulmonary circuit

External respiration

Internal respiration

Systemic capillary

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Figure 15-12
# Partial Pressures (mm Hg) and Normal Gas Concentrations (%) in Air

<table>
<thead>
<tr>
<th>SOURCE OF SAMPLE</th>
<th>NITROGEN (N₂)</th>
<th>OXYGEN (O₂)</th>
<th>WATER VAPOR (H₂O)</th>
<th>CARBON DIOXIDE (CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhaled air (dry)</td>
<td>597 (78.6%)</td>
<td>159 (20.9%)</td>
<td>3.7 (0.5%)</td>
<td>0.3 (0.04%)</td>
</tr>
<tr>
<td>Alveolar air (saturated)</td>
<td>573 (75.4%)</td>
<td>100 (13.2%)</td>
<td>47 (6.2%)</td>
<td>40 (5.2%)</td>
</tr>
<tr>
<td>Exhaled air (saturated)</td>
<td>569 (74.8%)</td>
<td>116 (15.3%)</td>
<td>47 (6.2%)</td>
<td>28 (3.7%)</td>
</tr>
</tbody>
</table>

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Gas Transport

- Arterial blood entering peripheral capillaries delivers oxygen and removes carbon dioxide
- Gas reactions with blood are completely reversible
- In general, a small change in plasma $P_{O_2}$ causes a large change in how much oxygen is bound to hemoglobin
Key Note

Hemoglobin binds most of the oxygen in the bloodstream. If the $P_{O_2}$ in plasma increases, hemoglobin binds more oxygen; if $P_{O_2}$ decreases, hemoglobin releases oxygen. At a given $P_{O_2}$ hemoglobin will release additional oxygen if the pH falls or the temperature rises.
Carbon Dioxide Transport

• Aerobic metabolism produces CO₂
• 7% travels dissolved in plasma
• 23% travels bound to hemoglobin
  • Called carbaminohemoglobin
• 70% is converted to H₂CO₃ in RBCs
  • Catalyzed by carbonic anhydrase
  • Dissociates to H⁺ and HCO₃⁻
  • HCO₃⁻ enters plasma from RBC
Carbon Dioxide Transport in the Blood

- CO₂ diffuses into bloodstream
- 7% remains dissolved in plasma (as CO₂)
- 93% diffuses into RBCs
  - 23% binds to Hb, forming carbaminohemoglobin, Hb•CO₂
  - 70% converted to H₂CO₃ by carbonic anhydrase
    - H₂CO₃ dissociates into H⁺ and HCO₃⁻
    - HCO₃⁻ moves out of RBC in exchange for Cl⁻ (chloride shift)
  - H⁺ removed by buffers, especially Hb

Figure 15-13
Carbon dioxide (CO$_2$) primarily travels in the bloodstream as bicarbonate ions (HCO$_3^-$), which form through dissociation of the carbonic acid (H$_2$CO$_3$) produced by carbonic anhydrase inside RBCs. Lesser amounts of CO$_2$ are bound to hemoglobin or dissolved in plasma.
Plasma

Alveolar air space

Red blood cells

Pulmonary capillary

Cells in peripheral tissues

Systemic capillary

O₂ pickup

O₂ delivery

O₂ pickup

O₂ delivery

O₂

Hb

Hb

O₂

O₂

Hb

O₂

O₂

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Figure 15-14(a)
Figure 15-14(a)

Plasma

Alveolar air space

Red blood cell

Pulmonary capillary

O₂ pickup

Hb

O₂

O₂Hb

O₂ pickup
Plasma

Alveolar air space

O₂ pickup

Red blood cells

Pulmonary capillary

O₂ delivery

Systemic capillary

O₂

Hb

Hb + O₂

O₂
Figure 15-14(b)

Systemic capillary

CO₂ pickup
Figure 15-14(b)

CO$_2$ pickup

Systemic capillary

H$_2$CO$_3$

H$_2$O

Hb CO$_2$

CO$_2$

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Chloride shift

Hb

Hb

H+ + HCO3–

HCO3–

Cl–

H2CO3

H2O

Hb

CO2

Systemic capillary

CO2 pickup

Figure 15-14(b)
Figure 15-14(b)

CO₂ delivery → CO₂ pickup

Systemic capillary

Pulmonary capillary

Chloride shift

H⁺ + HCO₃⁻ → H₂CO₃ → H₂O

CO₂ delivery

CO₂ pickup
Figure 15-14(b)

CO2 delivery

CO2 pickup

Systemic capillary

Pulmonary capillary

Hb

H+ + HCO3–

HCO3–

Cl–

H2CO3

H2O

H+ + HCO3–

H2CO3

H2O

CO2

Hb

CO2

CO2

CO2

Chloride shift
CO₂ delivery

H⁺ + HCO₃⁻ → H₂CO₃ → H₂O

Hb

CO₂ pickup

HCO₃⁻ → H⁺ + Cl⁻
The Control of Respiration

Meeting the Changing Demand for Oxygen

- Requires integration cardiovascular and respiratory responses
- Depends on both:
  - Local control of respiration
  - Control by brain respiratory centers
Local Control of Respiration

- Arterioles supplying pulmonary capillaries *constrict* when oxygen is low
- Bronchioles *dilate* when carbon dioxide is high
The Control of Respiration

Control by Brain Respiratory Centers

- Respiratory centers in brainstem
  - Three pairs of nuclei
    - Two pairs in *pons*
    - One pair in *medulla oblongata*
  - Control respiratory muscles
  - Set rate and depth of ventilation
  - Respiratory rhythmicity center in medulla
    - Sets basic rhythm of breathing
The Control of Respiration

Basic
Regulatory
Patterns of
Respiration

Figure 15-15(a)

INHALATION
(2 seconds)

- Inspiratory muscles contract
- Inspiration occurs

QUIET BREATHING

- Dorsal respiratory group active

EXHALATION
(3 seconds)

- Passive expiration occurs
- Inspiratory muscles relax
- Dorsal respiratory group inhibited
The Control of Respiration

Basic Regulatory Patterns of Respiration

Figure 15-15(b)
Reflex Control of Respiration

- Inflation reflex
  - Protects lungs from overexpansion
- Deflation reflex
  - Stimulates inspiration when lungs collapse
- Chemoreceptor reflexes
  - Respond to changes in pH, $P_{O_2}$, and $P_{CO_2}$ in blood and CSF
The Control of Respiration

Control by Higher Centers

• Exert effects on pons or on respiratory motorneurons
  • Voluntary actions
    • Speech, singing
  • Involuntary actions through the limbic system
    • Rage, eating, sexual arousal
Key Note

Interplay between respiratory centers in the pons and medulla oblongata sets the basic pace of breathing, as modified by input from chemoreceptors, baroreceptors, and stretch receptors. CO$_2$ level, rather than O$_2$ level, is the main driver for breathing. Protective reflexes can interrupt breathing and conscious control of respiratory muscles can act as well.
The Control of Respiration

Figure 15-16

[Diagram showing the control of respiration with labels for higher centers, respiratory centers of pons, Chemoreceptors and baroreceptors of carotid and aortic sinuses, stretch receptors of lungs, motor neurons controlling diaphragm, motor neurons controlling other respiratory muscles, and ventral respiratory group (VRG).]
Respiratory Changes at Birth

Conditions Before Birth
- Pulmonary arterial resistance is high
- Rib cage is compressed
- Lungs are collapsed
- Airways, alveoli are filled with fluid

Conditions After Birth
- An *heroic* breath fills lungs with air, displaces fluid, and opens alveoli
- Surfactant stabilizes open alveoli
Respiratory System and Aging

Respiratory System Loses Efficiency

- Elastic tissue deteriorates
  - Lowers vital capacity
- Rib cage movement restricted
  - Arthritic changes
  - Costal cartilages loses flexibility
- Some emphysema usually appears
The Respiratory System in Perspective

FIGURE 15-17
Functional Relationships Between the Respiratory System and Other Systems
The Integumentary System

- Protects portions of upper respiratory tract; hairs guard entry to external nares
• Movements of ribs important in breathing; axial skeleton surrounds and protects lungs
Muscular activity generates carbon dioxide; respiratory muscles fill and empty lungs; other muscles control entrances to respiratory tract; intrinsic laryngeal muscles control airflow through larynx and produce sounds.
The Nervous System

- Monitors respiratory volume and blood gas levels; controls pace and depth of respiration
The Endocrine System

- Epinephrine and norepinephrine stimulate respiratory activity and dilate respiratory passageways
The Cardiovascular System

- Red blood cells transport oxygen and carbon dioxide between lungs and peripheral tissues
- Bicarbonate ions contribute to buffering capability of blood
The Lymphatic System

- Tonsils protect against infection at entrance to respiratory tract; lymphatic vessels monitor lymph drainage from lungs and mobilize specific defenses when infection occurs.

- Alveolar phagocytes present antigens to trigger specific defenses; mucous membrane lining the nasal cavity and upper pharynx traps pathogens, protects deeper tissues.
The Digestive System

- Provides substrates, vitamins, water, and ions that are necessary to all cells of the respiratory system
- Increased thoracic and abdominal pressure through contraction of respiratory muscles can assist in defecation
The Urinary System

- Eliminates organic wastes generated by cells of the respiratory system; maintains normal fluid and ion balance in the blood
- Assists in the regulation of pH by eliminating carbon dioxide
The Reproductive System

- Changes in respiratory rate and depth occur during sexual arousal