CHAPTER 23
RESPIRATORY SYSTEM

CHAPTER OVERVIEW: This chapter describes the structure and function of the organs of the respiratory system and explains the physiology of ventilation, gas exchange and gas transport. The central nervous system reflexes controlling respiratory rate and depth are considered in detail. The underlying physical principles associated with the diffusion of gases are reviewed in relation to their importance in gas exchange and gas transport.

OUTLINE (four or five fifty-minute lectures):
Seeley, A&P, 5/e

:. t.	**Topic Outline, Chapter 23**	**Figures & Tables**	**Transpare Acetates**
	I. Anatomy and Histology, p. 738	Clinical Focus, pp.773-774 Systems Interactions, p.776	
	1. Upper Respiratory Tract = Nasal Cavity, Pharynx, and Associated Structures	Fig. 23.1, p.739	TA-469
	2. Lower Respiratory Tract = Larynx, Trachea, Bronchi, and Lungs		
	A. Nose and Nasal Cavity		
	1. External Nose	Fig. 7.10b, p.193	
	2. Nasal Cavity - Lined with Mucous Membrane of Psuedostratified Ciliated Columnar Epithelium	Fig. 23.2, p.740 Predict Quest. 1	TA-470
	a. External Nares = Nostrils		
	b. Internal Nares = Choanae		
	c. Vestibule - Lined with Stratified Squamous Epithelium		
	d. Internasal Septum		
	e. Hard Palate		
	f. Nasal Conchae Each with Associated Meatus		
	g. Paranasal Sinuses	Fig. 7.11, p.194	TA-128
	h. Nasolacrimal Duct	Fig. 15.10, p.473	TA-307
	3. Nasal Cavity Functions as Air Passageway, Warms, Moisturizes and Filters Air; Houses Smell Receptors; Resonating chamber for Speech		
	B. Pharynx - Common Opening of Digestive and Respiratory Systems	Fig. 23.2, p.740	TA-470
	1. Nasopharynx		
	a. Internal Nares to Uvula		
	b. Mucous Membrane Similar to Nasal Cavity		
	c. Opening to Auditory Tubes	Fig. 15.23, p.490	TA-315
	d. Pharyngeal Tonsil on Posterior Surface		

- 2. Oropharynx
    - a. Uvula to Epiglottis
    - b. Oral Cavity Through Fauces
    - c. Lined by Stratified Squamous Epithelium
    - d. Palatine and Lingual Tonsils
- 3. Laryngopharynx
    - a. Tip of Epiglottis to Separate Openings to Larynx and Esophagus
    - b. Lined with Stratified Squamous Epithelium

C. Larynx — Fig. 23.3, p.741 — TA-471

- 1. Nine Cartilages (Most Hyaline Cartilage)
    - a. Six Paired
    - b. Three Unpaired
    - c. Connected by Muscles and Ligaments
- 2. Lined by Pseudostratified Squamous Epithelium Except True and False Vocal Cords
- 3. Thyroid Cartilage = Adam's Apple
- 4. Cricoid Cartilage = Base of Larynx
- 5. Epiglottis
    - a. Elastic Cartilage
    - b. Covers Opening to Larynx During Swallowing
- 6. Vocal Apparatus — Fig. 23.4, p.742 — TA-472
    - a. Arytenoid Cartilages
    - b. Corniculate Cartilages
    - c. Cuneiform Cartilages
    - d. Vestibular Folds - Protective Functions
    - e. Vocal Folds = True Vocal Cords

D. Trachea — Fig. 23.5a, p.743; Clinical Note, p.742 — TA-473

- 1. Dense Regular Connective Tissue and Smooth Muscle
- 2. Reinforced with C-Shaped Pieces of Cartilage — Predict Quest. 2
- 3. Lined with Pseudostratified Ciliated Columnar Epithelium — Fig. 23.5b, p.743
    - a. Constant Irritation Can Change to Moist Stratified Squamous Epithelium
    - b. Loss of Cilia Leads to Loss of Protective Function

E. Tracheobronchial Tree

- 1. First Branch into R. and L. Primary Bronchi — Fig. 23.6, p.744 — TA-474
- 2. Conducting Zone — Predict Quest. 3
    - a. R. Bronchus is Shorter, Wider, and more Vertical than the L. — Fig. 23.7, p.746 — TA-475
    - b. Extends from Trachea to

Terminal Bronchioles
c. Primary Bronchi to Secondary (Lobar) Bronchi to Tertiary (Segmental) Bronchi to Bronchioles, Then Terminal Bronchioles
d. Less Cartilage, MoreSmooth Muscle as Divisions Are Smaller ñ Asthsma

1. Respiratory Zone
    a. Terminal Bronchioles Divide into Respiratory Bronchioles, Then to Alveolar Ducts, Alveolar Sacs, and Alveoli
    b. Alveoli ñ Simple Aquamous Epithelium, Macrophages Present

F. Lungs

1. Primary Organs of Respiration
2. Conical Shape
    a. Base on Diaphragm
    b. Apex 2.5 cm Superior to Clavicle
3. R. Lung Larger than L. — Fig. 23.8, p.747 — TA-476
    a. R. Lung has Greater Mass
    b. R. Lung has Three Lobes and Ten Brochopulmonary Segments
    c. L. Lung has Two Lobes and Nine Bronchopulmonary Segments

G. Thoracic Wall and Muscles of Respiration — Fig. 23.9a, p.748 — TA-477; Clinical Note, p.747; Fig. 23.9b, p.748 — TA-477

1. Muscles of Inspiration (Diaphragm , Internal Intercostals amd Abdominals) — Fig. 23.9c, p.749
    a. Inspiration ñ Expansion of Rib Cage
    b. Anterior-Posterior Dimension also Increased
1. Muscles of Expiration (External Intercostals, Pectoralis minor, Scalenes)
2. Normal Breathing VS Labored Breathing

H. Pleura — Fig. 23.10, p.750 — TA-478

1. Lungs Within Thoracic Cavity
2. Each Lung Surrounded by Separate Pleural Membranes
    a. Parietal Pleura Covers Inner Thoracic Wall, Superior Surface of Diaphragm and Mediastinum
    b. Visceral Pleura Covers Surface of Lung
    c. Pleural Membranes Become

Continuous at Hilum

3. Pleural Cavity Filled with Pleural Fluid
   - a. Acts as Lubricant
   - a. Helps Hold Pleural Membranes Together
   - b. Lung Volume Increases as Thoracic Cavity Expands

I. Blood Supply

1. Pulmonary Circulation
   - a. Pulmonary Arteries Carry Deoxygenated Blood to Alveoli for Gas Exchange
   - b. Pulmonary Veins Carry Oxygenated Blood Back to Heart

2. Bronchial Circulation
   - a. Bronchial Arteries Carry Oxygenated Blood to Tissues of Respiratory Passages Down to Bronchioles
   - b. Bronchial Veins Carry Deoxygenated Blood from Proximal Bronchi to Azygous System
   - c. Distal Bronchial Drainage Enters Pulmonary Veins

J. Lymphatic Supply

1. Superficial Lymphatic Vessels
2. Deep Lymphatic Vessels
3. Cancer Spreads Through These Vessels

II. Ventilation , p. 751

A. Pressure Differences and Air Flow — Clinical Note, p.751

1. Ventilation = Process of Moving Air Into and Out of Lungs — Table 23.1, p.752; Fig. 23.11, p.753 TA-479

2. Flow Proportional to Pressure Difference Between Atmospheric Air and Alveolar Air — Fig. 23.11b-c, p.753 TA-479-48; Fig. 23.11d, p.753 TA-480

A. Pressure and Volume
1. General Gas Law
2. As Volume Increases, Air Pressure Decreases

A. Air Flow into and out of Alveoli
1. Flow Inversely Proportional to Resistance to Flow - Related to Bronchiolar Constriction
2. Inspiration Occurs When Thoracic Volume Increased
3. Expiration Occurs When thoracic Volume Decreased

B. Changing Alveolar Volume

1. Primary Determinants
a. Elastic Recoil of Tissues
b. Surface Tension of Fluid Film Lining Alveoli

2. Normally Resisted by
a. Surfactant Which Reduces Surface Tension — Clinical Note 1, p.754
b. Intrapleural Pressure Below Atmospheric Pressure — Clinical Note 2, p.754

Pleural Pressure Alveolar Pressure Changes During Inspiration and — Fig. 23.12, p.755 TA-481

Expiration — Predict Quest. 4

III. Measuring Lung Function, p. 755

A. Compliance of the Lungs and the Thorax

1. Compliance = Measure of the Expansibility of the Lungs and Thorax — Clinical Note, p.755
   a. Volume Increase for Each Unit of Pressure Change in Intrapulmonary Pressure
   b. Normal Value is 0.13L per cm Water
2. The Greater the Compliance the Easier it is to Expand the Lungs
3. Abnormally High Compliance Results from Loss of Elastic Tissue as in Emphysema
4. Abnormally Low Compliance Results from
   a. Deposition of Inelastic Fibers - Pulmonary Fibrosis
   b. Collapse of the Alveoli - Respiratory Distress Syndrome and Pulmonary Edema
   c. Airway Obstruction - Asthma, Bronchitis, Lung Cancer
   d. Deformities of the Thoracic Wall - Kyphosis and Scoliosis

B. Pulmonary Volumes and Capacities — Fig. 23.13a, p.756

1.Volumes Measured Using Spirometry
   a. Tidal Volume — Fig. 23.13b, p.756 — TA-482
      1). Volume of Air Moved During Normal Inspiration or Expiration
      2). About 500 ml
   b. Inspiratory Reserve Volume
      1). Volume of Air Inspired Forcefully After Inspiration of Tidal Volume
      2). About 3000 ml
   c. Expiratory Reserve Volume
      1). Volume of Air Expired Forcefully After Expiration of Tidal Volume
      2). About 1100 ml
   d. Residual Volume
      1). Volume of Air Remaining in Respiratory Passages Following Maximum Forced Expiration
      2). About 1200 ml
3. Pulmonary Capacities (Sum of Two or More Pulmonary Volumes) — Fig. 23.13b, p.756 — TA-482
   a. Inspiratory Capacity
      1). Tidal Volume Plus Inspiratory

Reserve Volume
2). Maximum Volume a Person can Inspire After a Normal Expiration
3). About 3500 ml
b. Functional Residual Capacity
1). Expiratory Reserve Volume Plus Residual Volume
2). Amount of Air Remaining in the Lungs After Normal Expiration
3). About 2300 ml
c. Vital Capacity
1). Sum of Inspiratory Reserve Volume, Tidal Volume and the Expiratory Reserve Volume
2). Maximum Volume of Air that Can Be Expelled After Maximum Inspiration
3). About 4600 ml
d. Total Lung Capacity
1). Sum of Inspiratory Reserve Volume, Expiratory Reserve Volume, Tidal Volume and Residual Volume
2). About 5800 ml

4. Volumes of Vital Capacity Influenced by
a. Sex - Adult Females 20-25% Below Adult Males
b.Age - Greatest in Young Adults
c. Body Size
1). Tall > Short
2). Thin > Obese
d. Physical Conditioning
1). Training Increased by 30-40%
2). Disease Deceased Below Survival (Less than 500 -1000 ml)

5. Forced Expiratory Vital Capacity
a. Rate at Which Lung Volume Changes During Measurement of Vital Capacity
b. Clinically Important Pulmonary Test

C. Minute Respiratory Volume and Alveolar Ventilation Rate   Predict Quest. 5

1. Minute Respiratory Volume
a. Total Amount of Air Moved Through Respiratory System Each Minute
b. Tidal Volume X Respiratory Rate
c. 500 ml X 12 Breaths/min = 6

L/min		
2. Dead Air Space		
a. Part of the Respiratory System Where Gas Exchange Does not Take Place		
b. Anatomical Dead Air Space (150 ml) - Volume of Respiratory Passages from Nasal Cavity, to Terminal Bronchioles		
c. Physiological Dead Air Space (Variable) Anatomical Dead Air Space Plus Volume of Any Non-Functional Alveoli	Clinical Note, p.757	
3.Alveolar Ventilation		
a. Volume of Air that is Available for Gas Exchange		
b. Inspired Air Fills Dead Air Space First		
c. AVR = RR (TV - DAS)		
IV. Physical Principles of Gas Exchange, p. 757	System Interactions, p.776	
A. Partial Pressure		
1. Dalton's Law	Table 23.1, p.752	
2. Partial Pressure of a Gas = Pressure Exerted by Each Gas in a Mixture of Gasses	Table 23.2, p.758	
3. Vapor Pressure (P_{H2O}) = Partial Pressure of Water in the Gaseous Form		
B. Diffusion of Gases Through Liquids		
1. Henry's Law	Table 23.1, p.752	
2. Conc. of Dissolved Gas = Partial Pressure of a Gas X Solubility Coef. of the Gas		
3. Direction of Diffusion from Higher Partial Pressure toward Lower Partial Pressure	Predict Quest. 6	
C. Diffusion of Gases Through the Respiratory Membrane		
1. Respiratory Membranes of Lungs are in Respiratory Bronchioles, Alveolar ducts and Alveoli	Fig. 23.14a, p.759	
2. Structure of Respiratory Membrane	Fig. 23.14b, p.759	TA-483
a. Thin Layer of Fluid Lining Alveolus		
b. Alveolar Epithelium (Simple Squamous Epithelium)		
c. Basement Membrane of Alveolar Epithelium		
d. Thin Interstitial Space		
e. Basement Membrane of the Capillary Endothelium		
f. Capillary Endothelium (Simple Squamous Epithelium)		
3. Respiratory Membrane		

Thickness (Influences Rate of Gas Diffusion)
a. Normally 0.5 mm
b. Increased by Pulmonary Edema
3). Increased Thickness = Decreased Gas Exchange
4. Diffusion Coefficient
a. Measure of How Easily a Gas Diffuses through a Liquid
b. Through Resp. Membrane Roughly Equivalent to Diffusion Coefficient through Water
c. Carbon Dioxide's Diffusion Coefficient 20 Times Greater than that of Oxygen
5. Surface Area
a. Normally About 70 m^2
b. Decreased by Disease, Edema and Atelectasis
6. Partial Pressure Difference — Fig. 23.14b, p.759 — TA-483
a. Difference in Partial Pressure of Gas Between Alveolar Air and Pulmonary Blood
b. Direction of Diffusion from Higher Partial Pressure toward Lower Partial Pressure
c. Partial Pressures in Alveolar Air Influenced by Alveolar Ventilation Rate

D. Relationship Between Ventilation and Capillary Blood Flow
1. Blood Not Completely Oxygenated = Shunted Blood
2. Blood Flow Normally Matched to Ventilation — Clinical Note, p.761
a. Decreased Gas Exchange Leads to Decreased P_{O2} and Increased P_{CO2} in Arteriolar Blood
1). Stimulates Arteriolar Constriction
2). Decreased Blood Flow to Alveoli with Poor Ventilation
b. Increased Ventilation (as in Response to Exercise) Decreases P_{CO2} and Increases P_{O2} — Predict Quest. 7
1). Arteriolar Smooth Muscle Relaxes
2). Blood Flow to Well Ventilated Alveoli Increases

V. Oxygen and Carbon Dioxide Transport in the Blood, p. 761
A. Oxygen Diffusion Gradients — Fig. 23.15, p.762 — TA-484
1. Blood Arriving at Alveoli Has Lower P_{O2} (40

mm Hg) than Alveolar Air (104 mm Hg)
    2. Blood Leaving Lungs has P_{O2} of 95 mm Hg
    3. Blood Entering Capillaries Same as Systemic Arterial Blood, Intracellular P_{O2} = 20 mm Hg
    4. Blood Leaving Capillary Has Lower P_{O2} (40 mm Hg)

B. Carbon Dioxide Diffusion Gradients — Fig. 23.15, p.762 — TA-484
    1. CO_2 Produced as Byproduct of Cellular Respiration
        a. Intracellular P_{CO2} About 46 mm Hg
        b. Interstitial P_{CO2} About 45 mm Hg
    2. Tissue Capillary P_{CO2} Goes from 40 mm Hg at Arterial End to About 45 mm Hg at Venular End
    3. Pulmonary Capillary P_{CO2} Goes from 45 mm Hg at Arterial End to About 40 mm Hg at Venular End

C. Hemoglobin and Oxygen Transport
    1. 97% of Total Oxygen Transported in Combination with Hemoglobin; Remaining 3% Oxygen Dissolved
    2. Effect of P_{O2} - Oxygen-Hemoglobin Dissociation Curve — Fig. 23.16, p.763 — TA-485
        a. Hemoglobin Saturated at P_{O2} \$ 80 mm Hg
        b. In a Resting Person, at Normal Tissue Capillary P_{O2} of 40 mm Hg Hemoglobin is 75% Saturated
        c. During Strenuous Exercise, Tissue Capillary P_{O2} Drops to 15 mm Hg and Hemoglobin is only 25% Saturated — Fig. 23.17, p.764 — TA-486
    3. Effect of pH, P_{CO2}, and Temperature
        a. Effect of pH = Bohr Effect — Fig. 23.18, p.765 — TA-487
        b. Increased CO_2 Leads to Decreased pH
        1). Carbonic Anhydrase Enzyme - Reversible Reaction
        2). Located in Erythrocytes and Other Cells
        c. Increased CO_2, Decreased pH and/or Increased Temperature Lead to Decreased Ability of Hemoglobin to Bind Oxygen (Curve shifted to the Right) — Predict Quest. 8
        4. Effect of BPG; 2,3 bisphosphoglycerate (BPG, aka, diphosphoglycerate)
            a. Produced by Erythrocytes
            b. BPG Decreases Ability of

Hemoglobin to Bind Oxygen
c. BPG Levels Increase at High Altitudes — Predict Quest. 9

4. Transport of Carbon Dioxide
   a. Mechanisms of Transport — Fig. 23.19, p. 766 — TA-488
      1). 8% Dissolved in the Plasma
      2). 20% Transported as Carbamino Compounds,
   a. Carbon Dioxide and Blood pH — Predict Quest. 10
      1. Blood pH = Plasma pH
      2. Carbonic Acid Dissociates to Bicarbonate and H^+
      3. Respiratory System Regulates Blood pH by Changing Plasma Carbon Dioxide Levels

VI. Rhythmic Ventilation, p. 767 — Clinical Focus, pp.751

A. Respiratory Areas in the Brainstem
   1. Medullary Respiratory Center — Fig. 23.20 p.767 — TA-489
      a. Two Dorsal Respiratory Groups Stimulate Contraction of the Diaphragm
      b. Two Ventral Respiratory Groups Are Active During Inspiration and Expiration
   1. Pontine Respiratory Group — Fig. 23.20, p.767 — TA-489
      a. Collection of Neurons in Pons; Exact Function Unknown
      b. Pons Centers work Together to Ensure Rhythmic Respiratory Cycles
      B. Generation of Rhythmic Ventilation Believed to Be a 3 Step Process

VII. Modification of Ventilation, p. 768

A. Cerebral and Limbic System Control — Fig. 23.21, p.769 — TA-490
   1. Voluntary Control Over Respiration Possible During Singing, Voluntary Apnea, Voluntary Hyperventilation — Fig. 23.21, p.769 — TA-490; Fig. 23.22, p.770 — TA-491
   2. Emotions Via Limbic System Can Alter Respiration Patterns

B. Chemical Control of Ventilation
   1. Chemoreceptors
      a. Central Chemoreceptors in Chemosensitive Center of Ventral Medulla Oblongata
      b. Peripheral Chemoreceptors in Carotid and Aortic Bodies
   2. Effect of pH
      a. Chemosensitive Area Bathed in

Cerebrospinal Fluid
b. Indirectly Sensitive to Changes in Blood pH
c. Decreased pH Stimulates Respiratory Center and Increases Ventilation

3. Effect of Carbon Dioxide — Predict Quest. 11; Clinical Note, p.770
  a. Major Regulator of Respiration During Resting Conditions
  b. 5% Increase in P_{CO2} of 5 mm Hg Causes 100% Increase in Ventilation
  c. Hypercapnia Produces Increased Ventilation
  d. Hypocapnia Produces Apnea
  e. Exerts Effect on Respiration Through Effect on pH (Carbonic Anhydrase Reaction)
    1). Chemosensitive Area is More Important in Regulation of P_{CO2} and pH
    2). Carotid and Aortic Bodies Responsible for, at Most, 15-20% of Total Response
4. Effect of Oxygen ñ (Normally Small) — Fig. 23.22, p.771 — TA-491
  a. P_{O2} Must be Reduced to About 50% of Normal Before Large Stimulatory Effect Seen - Oxygen-Hemoglobin Binding Properties Involved
  b.Carotid and Aortic Chemoreceptors Respond by Stimulating Respiratory Center — Predict Quest. 12; Clinical Focus, p.751

C. Hering-Breuer Reflex
  1. Prevents Overinflation of the Lungs
  2. Stretch Receptors in Lungs
  3. In Adult Humans Important Only When Tidal Volume Large

D. Effect of Exercise on Ventilation
  1. Ventilation Increases Abruptly At Onset of Exercise
  2. Ventilation Increases Further Gradually 4-6 minutes After Onset of Exercise
  3. Highest Level of Exercise Without Big Change in Blood pH Is Anaerobic Threshold

E. Other Modifications of Ventilation
  1. Irritants Can Produce Sneeze or Cough Reflexes

VIII. Respiratory Adaptations to Training, p. 772
  1. Athletic Performance Increases in Response to Training
  2. Increased Cardiovascular Efficiency Results in Greater Blood Flow Through Lungs

IX. Systems Pathology: Asthma, p. 775 — Predict Quest. 13

IMPORTANT CONSIDERATIONS: If there are four lecture periods available the material splits nicely into one lecture on general anatomy and histology, one on pulmonary ventilation and respiratory volumes, one on gas exchange and transport in the blood, and one on the controls of respiration and the contributions of the respiratory system to homeostasis. If there are five or six lecture periods available the mechanisms of gas exchange and gas transport can be separated, and the neural and chemical control and integration of respiratory function can be covered in greater detail.

As always, much of this information is, or can be, integrated into the laboratory experiences which accompany the discussion of the respiratory system. The instructor must decide which aspects, such as spirometry and respiratory volumes, might be best presented when incorporated with personal experience in the laboratory.

Students with poor chemistry backgrounds will have significant difficulties understanding the diffusion and transport of gases associated with respiratory function.

SEE INSTRUCTOR'S MANUAL AND COURSE SOLUTIONS MANUAL FOR ADDITIONAL RESOURCES.