Chapter 24 Adapted from Tortora 10th ed.

LECTURE OUTLINE

A. Introduction (p.731)
   1. The cardiovascular system and the respiratory system cooperate in order to:
      i. supply oxygen which is required by cells to produce ATP
      ii. eliminate carbon dioxide which produces acidity that is toxic to cells
   2. The respiratory system provides for gas exchange, intake of oxygen and elimination of carbon dioxide, whereas the cardiovascular system transports these gases in the blood between the lungs and the body’s cells.
   3. Failure of either system results in rapid death due to oxygen starvation and accumulation of waste molecules.
   4. In addition to functioning in gas exchange, the respiratory system also:
      i. regulates blood pH
      ii. contains receptors for smell
      iii. filters inspired air
      iv. produces sound
      v. eliminates some water vapor and heat in exhaled air
   5. Otorhinolaryngology is the medical specialty that deals with the diagnosis and treatment of diseases of the ears, nose, and throat; a pulmonologist is a specialist in the diagnosis and treatment of lung diseases.

B. Respiratory System Anatomy (p. 732)
   1. The upper respiratory system includes:
      i. nose
      ii. pharynx
      iii. structures associated with the above two
   2. The lower respiratory system includes:
      i. larynx
      ii. trachea
      iii. bronchi
      iv. lungs
   3. Functionally, the respiratory system consists of two portions:
      i. conducting portion, which includes the structures that filter, warm, and moisten air, and conduct air into the lungs (total volume in an adult is about 150mL):
         a. nose
         b. pharynx
         c. larynx
         d. trachea
         e. bronchi
         f. bronchioles
         g. terminal bronchioles
      ii. respiratory portion, which consists of those structures where gas exchange occurs (total volume in an adult is about 5-6 liters):
         a. respiratory bronchioles
         b. alveolar ducts
         c. alveolar sacs
         d. alveoli
4. Nose:
   i. The nose consists of two major portions:
      a. external portion, which consists of a bony framework (formed by the frontal bone, nasal bones, and maxillae), flexible hyaline cartilage (including the septal cartilage, lateral nasal cartilages, and alar cartilages) covered with muscle and skin, and lined by a mucous membrane; the undersurface has two openings called the external nares or nostrils
         - the interior structures of the nose perform the following major functions:
            1. incoming air is warmed, moistened, and filtered
            2. olfactory stimuli are detected
            3. large, hollow resonating chambers modify speech sounds
      b. internal portion, which consists of a large cavity surrounded by bones;
         - it is located inferior to the nasal bones and superior to the mouth
         - anteriorly, it merges with the external nose
         - posteriorly, it communicates with the pharynx via two internal nares (choanae)
         - its walls have openings for ducts from the paranasal sinuses and the nasolacrimal ducts
   ii. Both portions of the nose contain the nasal cavity that is divided into right and left sides by the vertical nasal septum; the anterior portion of the nasal cavity, just inside the nostrils, is called the vestibule.
   iii. Air flows through the nose as follows:
      a. air enters the nostrils and is filtered by course hairs that line the vestibule
      b. air then whirls through the superior, middle, and inferior meatuses
      c. air comes into contact with the olfactory epithelium
      d. air is warmed by blood in capillaries
      e. air is moistened by mucus secreted by goblet cells (in the ciliated mucous membrane that lines the nasal cavity), by drainage from the nasolacrimal ducts, and perhaps by secretions from the paranasal sinuses
      f. air is cleansed as mucus traps dust particles; the cilia move the dust-laden mucus toward the pharynx
   iv. The nasal cavity receives its blood supply from the sphenopalatine branch of the maxillary artery and from the ophthalmic artery; blood drains into the sphenopalatin, facial, and ophthalmic veins.
   v. The nose is innervated by the olfactory (I) nerves and the ophthalmic and maxillary branches of the trigeminal (V) nerves.

5. Pharynx: (p. 735)
   i. The pharynx or throat is a funnel-shaped tube that is located anterior to cervical vertebrae, posterior to the nasal and oral cavities, and superior to the larynx; its wall is composed of skeletal muscles and is lined with mucous membrane.
   ii. The pharynx functions as a passageway for air and food and provides a resonating chamber for speech sounds.
   iii. The pharynx consists of three major portions:
      a. superior nasopharynx:
         - extends from the internal nares to the plane of the soft palate
         - its wall has openings for the internal nares and the auditory (Eustachian) tubes (with which the pharynx exchanges small volumes of air)
         - the posterior wall contains the pharyngeal tonsil (or adenoid)
         - it is lined by ciliated epithelium which moves dust-laden mucus inferiorly to be eliminated by swallowing or expectoration
b. intermediate oropharynx:
   - extends from the soft palate to the level of the hyoid bone
   - it communicates with the mouth via the fauces
   - it is a common passageway for air, food, and drink
   - its wall contains the pairs of palatine and lingual tonsils

c. inferior laryngopharynx or hypopharynx:
   - extends from the hyoid bone downward to the esophagus posteriorly and the larynx anteriorly
   - it is both a respiratory and digestive passageway

iv. The arteries that supply blood to the pharynx are the ascending pharyngeal, the ascending palatine branch of the facial, the descending palatine and pharyngeal branches of the maxillary, and the muscular branches of the superior thyroid artery; blood drains into the pterygoid plexus and the internal jugular veins.

v. The pharynx is innervated by the pharyngeal plexus which is formed by the pharyngeal branches of the glossopharyngeal (IX), vagus (X), and cranial portions of the accessory (XI) nerves and the superior cervical sympathetic ganglia.

6. Larynx:
   i. The larynx or voice box is a short passageway that extends from the laryngopharynx to the trachea, anterior to C4-C6.
   ii. The wall of the larynx contains nine pieces of cartilage:
      a. thyroid cartilage (Adam’s apple) is composed of two fused plates of hyaline cartilage that form the anterior wall of the larynx
         - it is usually larger in males than in females
         - it is connected to the hyoid bone by the thyrohyoid membrane
      b. epiglottis is a large leaf-shaped piece of elastic cartilage whose stem is attached to the anterior rim of the thyroid cartilage
         - during swallowing, elevation of the larynx causes the free edge of the epiglottis to close the glottis and thus prevent food and liquids from entering the rima glottidis
      c. cricoid cartilage is a ring of hyaline cartilage that forms the inferior wall of the larynx
         - it is attached to the first tracheal cartilage by the cricotracheal ligament and to the thyroid cartilage by the cricothyroid ligament
      d. two arytenoid cartilages are triangular pieces of mostly hyaline cartilage located at the posterior, superior border of the cricoid cartilage
         - they are involved in moving the vocal folds
      e. two corniculate cartilages are horn-shaped pieces of elastic cartilage located at the apex of each arytenoid cartilage
      f. two cuneiform cartilages are club-shaped pieces of elastic cartilage located anterior to the corniculate cartilages
   iii. The inner lining of most of the larynx is a ciliated mucous membrane whose cilia move dust-laden mucus upward toward the pharynx.
   iv. The mucous membrane is arranged to form two pairs of folds:
      a. upper ventricular folds (false vocal cords) which can come together to close the space between them called the rima vestibuli
      b. lower vocal folds (true vocal cords) which can vibrate in response to air flow to produce sound waves
         - the greater the pressure of air, the louder the sound
         - pitch is controlled by the tension on the vocal folds; the greater the tension, the higher the pitch (and vice-versa)
- between the ventricular folds and the vocal folds is a lateral expansion of the laryngeal cavity called the **laryngeal sinus** (ventricle)

v. The arteries of the larynx are the superior laryngeal and inferior laryngeal; blood drains into the superior and inferior laryngeal veins.

vi. The larynx is innervated by the superior and recurrent (inferior) laryngeal branches of the vagus (X) nerves.

7. **Trachea:** (p. 740)
   i. The **trachea** or windpipe is a tube located anterior to the esophagus and extends from the larynx down to the superior border of the fifth thoracic vertebra where it divides into right and left primary bronchi.
   ii. The wall has an inner lining that is a ciliated mucosa which moves dust-laden mucus up toward the pharynx.
   iii. The wall contains a stack of 16 to 20 C-shaped pieces of hyaline cartilage whose open sides face the esophagus
      - the ends of each C-shaped piece of cartilage are connected by the **trachealis muscle** (composed of smooth muscle fibers) and elastic connective tissue
      - these incomplete rings of cartilage permit slight expansion of the esophagus into the trachea during swallowing and also provide a semirigid support to prevent inward collapse of the tracheal wall
   iv. The arteries of the trachea are branches of the inferior thyroid, internal thoracic, and bronchial arteries; blood drains into the inferior thyroid veins.
   v. The trachea is innervated by the vagus (X) nerves and their recurrent laryngeal branches, and by branches from the sympathetic trunk and its ganglia.

8. **Bronchi:**
   i. At the superior border of the fifth thoracic vertebra, the trachea divides into the **right primary bronchus**, which enters the right lung, and the **left primary bronchus**, which enters the left lung;
      a. the right primary bronchus is more vertical, shorter, and wider than the left one
      b. the primary bronchi contain C-shaped pieces of cartilage and are lined by a ciliated mucosa
   ii. At the point where the trachea divides into the right and left primary bronchi, there is an internal ridge called the **carina** that is formed by a posterior and somewhat inferior projection of the last tracheal cartilage.
   iii. After entering the lungs, the primary bronchi divide into **secondary (lobar) bronchi**, three in the right lung and two in the left lung.
   iv. The secondary bronchi branch into **tertiary (segmental) bronchi** which in turn divide into **bronchioles**.
   v. The bronchioles branch into progressively smaller and smaller bronchioles and eventually into **terminal bronchioles**.
   vi. This continuous branching from the trachea forms the **bronchial tree**.
   vii. Several changes are observed as branching progresses in the bronchial tree:
      a. the epithelium changes from ciliated to nonciliated in the terminal bronchioles
      b. C-shaped pieces of cartilage in the primary bronchi are gradually replaced by plates of cartilage that finally disappear in the bronchioles
      c. as the cartilage decreases, the amount of smooth muscle tissue increases
         - smooth muscle encircles the lumen in spiral bands and its contraction is affected by the ANS and by various chemicals
vii. The bronchi receive their blood supply from the right and left bronchial arteries; blood drains into the right and left bronchial veins.

9. **Lungs:** (p. 744)
   i. The **lungs** are paired cone-shaped organs located in the thoracic cavity.
   ii. Separating the two lungs are the heart and other structures in the mediastinum.
   iii. The lungs are individually enclosed and protected by the **pleural membrane** which consists of two layers:
      a. superficial **parietal pleura** which is attached to the thoracic wall
      b. deeper **visceral pleura** which is attached to the lungs
         - between the pleurae is the **parietal cavity** which contains a lubricating fluid secreted by the membranes; inflammation of the pleural membrane, called **pleurisy** or **pleuritis**, may cause pain due to friction between the two layers of the pleural membrane
   iv. Gross anatomy:
      a. the lungs extend from the diaphragm to just slightly above the clavicles and lie against the ribs anteriorly and posteriorly
      b. the broad inferior portion of a lung is the **base**, and the narrow superior portion is the **apex**
      c. the **costal surface** of a lung lies against the ribs
      d. the **mediastinal (medial) surface** of a lung contains a region, the **hilus**, through which bronchi, pulmonary blood vessels, lymphatic vessels, and nerves enter and exit the lung
         - these structures are held together by the pleura and connective tissue, and form the **root** of the lung
      e. on its medial surface, the **left lung** has the concave **cardiac notch** which the heart rests against
      f. the right lung is thicker, broader, and shorter than the left lung
   v. **Lobes and Fissures:**
      a. In the **left lung**, the **oblique fissure** separates the **superior lobe** from the **inferior lobe**.
      b. In the **right lung**, the upper part of the oblique fissure separates the superior lobe from the inferior lobe, whereas the lower part of the oblique fissure separates the inferior lobe from the **middle lobe**; the **horizontal fissure** of the right lung subdivides the superior lobe to form the middle lobe.
      c. Each lobe receives its own secondary (lobar) bronchus
         - the **right** primary bronchus divides into the **superior, middle, and inferior secondary (lobar) bronchi**
         - the **left** primary bronchus divides into the **superior and inferior secondary (lobar) bronchi**
      d. In each lung, the secondary bronchi branch into 10 **tertiary (segmental) bronchi** that supply air to the **bronchopulmonary segments** of the lung.
   vi. **Lobules and Alveoli:**
      a. Each bronchopulmonary segment has many small compartments called **lobules**.
      b. Each lobule is wrapped in elastic connective tissue and contains a lymphatic vessel, an arteriole, a venule, and a branch of a terminal bronchiole called a **respiratory bronchiole**; a respiratory bronchiole subdivides into several **alveolar ducts**.
      c. Around the circumference of the alveolar ducts are numerous **alveoli** and **alveolar sacs**:
- an alveolus is a cup-shaped outpouching lined by simple squamous epithelium and supported by a thin elastic basement membrane
- alveolar sacs are two or more alveoli that share a common opening

d. The alveolar walls consist of two types of alveolar epithelial cells:
   1. type I alveolar are simple squamous epithelial cells that form a mostly continuous lining of the alveolar wall where gas exchange occurs
   2. type II alveolar (septal) cells that secrete alveolar fluid which keeps the alveolar cells moist; alveolar fluid contains surfactant which lowers the surface tension of alveolar fluid to prevent collapse of the alveoli

e. Associated with the alveolar wall are alveolar macrophages (dust cells) which are wandering phagocytes that remove dust and other debris in the alveolar spaces.

f. Also present are fibroblasts that produce reticular and elastic fibers; underlying the layer of type I alveolar cells is an elastic basement membrane.

g. Around the alveoli, the lobule’s arteriole and venule are interconnected by a capillary network; the blood capillaries consist of a single layer of endothelial cells and a basement membrane.

h. The exchange of respiratory gases between the air spaces in the lungs and the blood occurs by diffusion across the respiratory membrane; this membrane consists of four layers:
   1. a layer of type I and type II alveolar cells with wandering alveolar macrophages that constitutes the alveolar wall
   2. an epithelial basement membrane underneath the alveolar wall
   3. a capillary basement membrane that is often fused to the epithelial basement membrane
   4. the endothelial cells of the capillary

i. The respiratory membrane averages only 0.5 micrometers in thickness and it is estimated that the lungs contain about 300 million alveoli; therefore, there is an immense, extremely thin surface that permits rapid diffusion of significant volumes of the respiratory gases.

vii. Blood and Nerve Supply to the Lungs:
   a. The lungs have a double blood supply.
   b. Deoxygenated blood is delivered to the lungs by the right and left pulmonary arteries; oxygenated blood drains into the right and left superior and inferior pulmonary veins.
   c. Oxygenated blood is delivered to the bronchi and bronchioles of the lungs by the bronchial arteries.
   d. The two systems communicate and most blood returns via the pulmonary veins; some blood drains into the bronchial veins.
   e. The lungs are innervated from the pulmonary plexus which is formed by branches of the vagus (X) nerves and sympathetic trunks.
C. Mechanics of Pulmonary Ventilation (Breathing) (p. 750)

1. The exchange of gases between the atmosphere, blood, and cells is called respiration; it consists of three major processes:
   i. **pulmonary ventilation** or breathing, which includes inspiration and expiration of air between the lungs and the atmosphere
   ii. **external (pulmonary) respiration**, the exchange of gases between the air spaces in the lungs and the blood in pulmonary capillaries; the blood gains O₂ and loses CO₂
      ii. **internal (tissue) respiration**, the exchange of gases between the blood in systemic capillaries and the body’s cells; the blood loses O₂ and gains CO₂

2. Inspiration:
   i. **Inspiration (inhalation)** is the process of moving air into the lungs.
   ii. It occurs when air pressure within the alveoli of the lungs, called alveolar pressure, is lower than atmospheric pressure.
   iii. It is achieved by expanding the lungs, a process which increases the volume of the lungs and therefore decreases the air pressure within the lungs below atmospheric pressure.
   iv. The major inspiratory muscles are:
      a. **diaphragm** (the most important inspiratory muscle)
      b. **external intercostals**
         - contraction of these muscles increases the volume of the thoracic cavity
         - this causes a decrease in the intrapleural pressure which in turn pulls the walls of the lungs outward
   v. The increase in volume of the lungs causes a decrease in alveolar pressure.
   vi. Therefore, air rushes down the pressure gradient from the atmosphere into the lungs; inspiration ends when the pressure difference is eliminated.
   viii. Additional muscles (e.g., scalene muscles) participate during deep, labored inspiration.

3. Expiration:
   i. **Expiration (exhalation)** is the process of moving air out of the lungs.
   ii. It occurs when air pressure in the lungs is greater than atmospheric pressure.
   iii. Unlike inspiration, normal expiration is a passive process since no muscular contractions are involved.
   iv. It is achieved by relaxation of the inspiratory muscles; this results in a decrease in the volume of the thoracic cavity due to:
      a. recoild of elastic fibers that were stretched during inspiration
      b. inward pull of surface tension due to the film of alveolar fluid
   v. This causes a decrease in lung volume which in turn increases the alveolar pressure.
   vi. Therefore, air rushes down the pressure gradient from the alveoli into the atmosphere.
   vii. Forced expiration involves the contractions of abdominal and internal intercostal muscles.
   ix. Respirations can be used for laughing, sobbing, sneezing, coughing, talking, etc.; some modified respiratory movements that express emotion or clear the airways are listed in Table 24.1.
D. Regulation of Respiration (p. 752)

1. Role of the Respiratory Center:
   i. The respiratory muscles are controlled automatically by the *respiratory center* located in the brain stem.
   ii. The respiratory center consists of a dispersed group of neurons that is functionally divided into three areas:
      a. **medullary rhythmicity area** is located in the medulla oblongata:
         - it controls the basic rhythm of respiration
         - it contains an **inspiratory area** whose autorhythmic inspiratory neurons rhythmically send nerve impulses via the phrenic nerves to the diaphragm to cause the typical breathing cycle
         - it contains an **expiratory area** whose expiratory neurons are active only during forced expiration
      b. **pneumotaxic area** is located in the superior portion of the pons:
         - helps coordinate the transition between inspiration and expiration
         - it transmits inhibitory impulses to the inspiratory area to limit the duration of inspiration and therefore permit expiration before the lungs become overinflated
         - when the pneumotaxic area is more active, breathing rate is more rapid
      c. **apneustic area** is located in the inferior portion of the pons:
         - it also helps coordinate the transition between inspiration and expiration
         - it stimulates the inspiratory area to prolong inspiration and therefore inhibit expiration
         - such stimulation occurs only when the pneumotaxic area is inactive

2. Regulation of the Respiratory Center:
   i. The basic rhythm of respiration established by the inspiratory area of the respiratory center can be modified by several factors:
      a. **cortical influences** from the cerebral cortex that permit voluntary control over breathing
      b. **chemical stimuli** detected by the (a) **central chemoreceptors** (in the medulla oblongata) which monitor CO₂ and H⁺ concentrations in the cerebrospinal fluid, and (b) **peripheral chemoreceptors** (located in the aortic bodies and carotid bodies within the walls of systemic arteries) which monitor O₂, CO₂, and H⁺ concentrations in the blood
      c. **inflation (Hering-Breuer) reflex**, which is a protective reflex initiated by lung **baroreceptors** or **stretch receptors** to prevent overinflation of the lungs

E. Exercise and the Respiratory System (p. 755)

1. During exercise, cardiac output increases and thus the rate of blood flow through the lungs also increases; in addition, blood flows through a larger percentage of pulmonary capillaries.
2. Therefore, the blood picks up more O₂ and releases more CO₂.
3. This is accompanied by an increase in the depth and, during strenuous exercise, the rate of pulmonary ventilation.
4. At the end of an exercise session, pulmonary ventilation returns to the resting levels
F. Development of the Respiratory System  (p. 756)
   1. The respiratory system begins as an outgrowth of the foregut called the respiratory diverticulum; the latter’s endoderm develops into the epithelial lining and glands of the trachea, bronchi, and alveoli; the splanchnic mesoderm develops into the connective tissue, cartilage and smooth muscle of these structures.
   2. The epithelial lining of the larynx develops from the endoderm of the respiratory diverticulum; the cartilages and muscles develop from the fourth and sixth pharyngeal arches.
   3. The distal end of the elongating the respiratory diverticulum enlarges to form a tracheal bud which gives rise to the trachea; the tracheal bud then divides into bronchial buds which branch repeatedly and develop into bronchi, and all generations of bronchioles.
   4. During weeks 16-26, lung tissue become shighly vascularized and respiratory bronchioles, alveolar ducts, and primitive alveoli develop; afterwards (until roughly age eight), additional alveoli develop.
   5. The visceral pleura develop from splanchnic mesoderm and the parietal pleura develops from somatic mesoderm.

G. Aging and the Respiratory System  (p. 757)
   1. The effects of aging on the pulmonary system include:
      i. decreased elasticity and increased rigidity of lung airways and tissues, and chest wall
      ii. decrease in lung capacity and vital capacity
      iii. decrease in blood oxygen concentration
      iv. decreased activity of alveolar macrophages
      v. decreased ciliar action in the respiratory mucosa
   2. As a consequence of the above changes, elderly people are more susceptible to pneumonia, bronchitis, emphysema, and other pulmonary disorders.

H. Key Medical Terms Associated with the Respiratory System  (p. 760)
   1. Students should familiarize themselves with the glossary of key medical terms.