Respiratory System

Mechanics of breathing

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LECTURE OBJECTIVES:

1. Review the physiological anatomy of the pulmonary system and define conducting and respiratory zones.
2. Identify the major functions of the lungs (the respiratory and non-respiratory functions).
3. Define cellular respiration and external respiration and understand the steps of external respiration.
4. Describe the generation of a pressure gradient between the atmospheres and the alveoli.
5. List the major muscles involved in respiration and state the role of each.
6. Define intrapleural pressure, alveolar pressure, transpulmonary pressure, and elastic recoil pressure.
7. Diagram how pleural pressure, alveolar pressure, airflow, and lung volume change during a normal quiet breathing cycle. Identify on the figure the onset of inspiration, cessation of inspiration, and cessation of expiration.

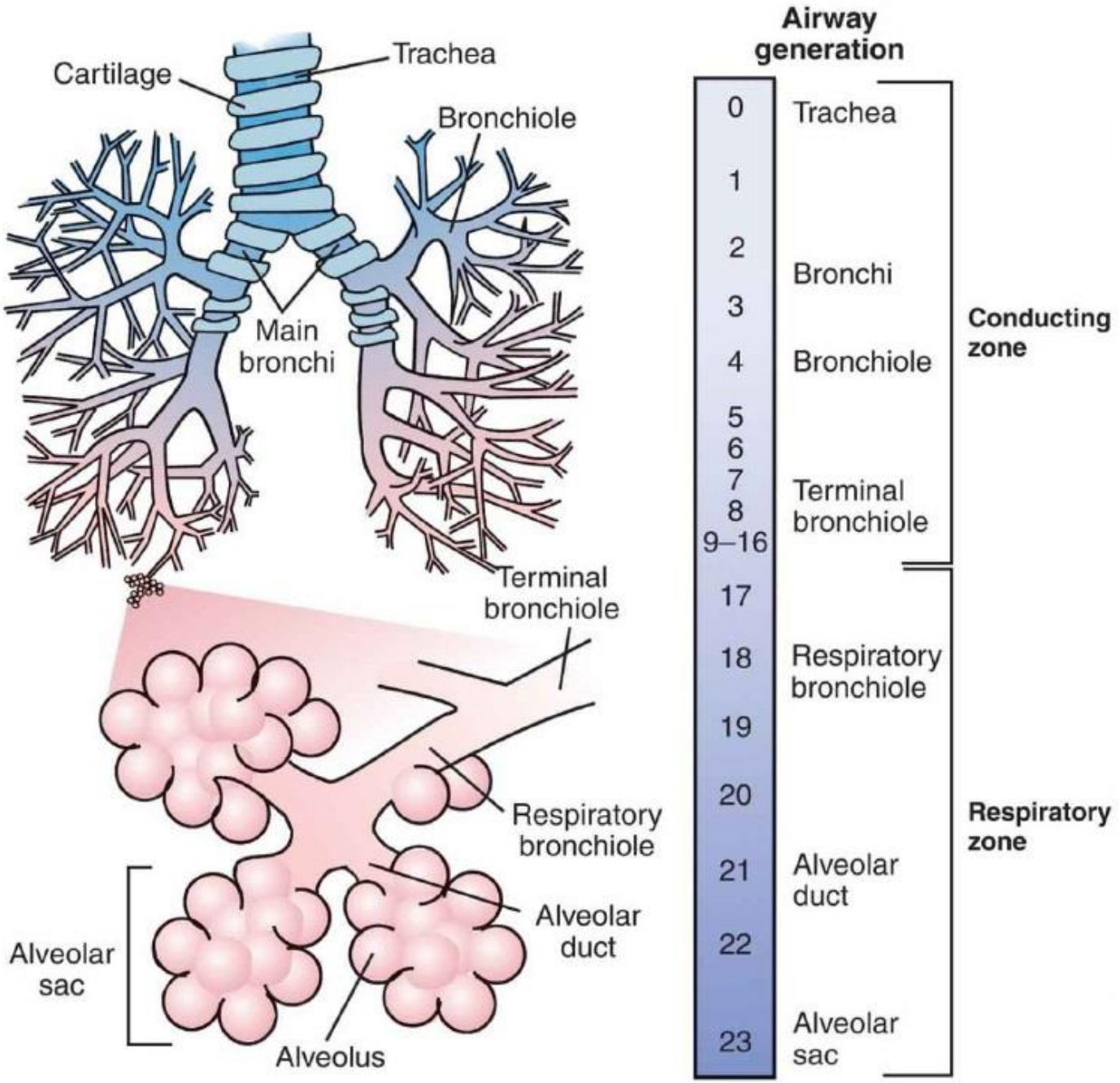
FUNCTIONS OF THE RESPIRATORY SYSTEM:

1. The primary role of the respiratory system is to maintain a constant internal environment by providing oxygen for metabolic needs and excreting CO_2.
   A. *External respiration*: includes mechanics of pulmonary ventilation, the transfer of gas across the respiratory membrane, and the transport of gas by the blood to and from the body cells.
   B. *Internal respiration*: is concerned with intracellular oxygen utilization.

2. Secondary roles of the respiratory system include:
   A. Aiding in acid-base balance.
   B. Enabling speech, singing, and other vocalization.
   C. The nose, a part of the respiratory system, serves as the organ of smell, and defends the body against inhaled particles (e.g. bacteria, pollen).
   D. Acting as a filter to prevent clots from entering the systemic circulation.
   E. Acting as a reservoir for blood.
   F. Regulating various hormonal and humoral concentrations by means of the pulmonary capillary endothelium.
   G. The respiratory muscles generate the large pressures needed during defecation, vomiting, and childbirth.

FUNCTIONAL ANATOMY OF THE LUNGS

- The lungs alone cannot bring air in and out of the lungs or exchange oxygen and carbon dioxide from the blood.
- Respiratory muscles and an airtight chest wall to create a negative pressure within the chest are essential for the proper functioning of the lungs.
- The lungs comprise two tree-like structures, the vascular tree and the airway tree, which are embedded in highly elastic connective tissue.
- The main airway, the **trachea**, branches into two **bronchi**. Each bronchus enters a lung and branches many times (on average **23 generations**) into progressively smaller bronchi, which, in turn, form **bronchioles**.
- The airways are divided into two functional zones:
  1. The first 16 generations of branches comprising the **conducting zone** and functioning to conduct air to the deeper parts of the lungs. Because the conducting airways **contain no alveoli**, and therefore take no part in gas exchange, they constitute the anatomic dead space. Its volume is about **150 ml**.
  2. The last 7 generations are **alveolated** and participate in gas exchange and comprise the **respiratory zone**. The 17^{th} to 19^{th} generations of bronchioles constitute the transitional respiratory bronchioles. The respiratory zone makes up most of the lung, its volume being about **2.5 to 3 liters** during rest.


Cartilage
Trachea
Bronchiole
Main bronchi
Terminal bronchiole
Respiratory bronchiole
Alveolar duct
Alveolar sac
Alveolus
Airway generation
0
1
2
3
4
5
6
7
8
9–16
17
18
19
20
21
22
23
Trachea
Bronchi
Bronchiole
Terminal bronchiole
Respiratory bronchiole
Alveolar duct
Alveolar sac
Conducting zone
Respiratory zone

FUNCTIONAL ANATOMY OF THE LUNGS (CONT.)

- The conducting zone has three important functions:
  1. Warm and humidify inspired air
  2. Distribute air evenly to all regions of the lungs
  3. Serve as part of the body's defense system (removal of dust, bacteria, and noxious gases from the lungs).
- The conducting zone has its own separate circulation, the **bronchial circulation**, which originates from the descending aorta and drains into the pulmonary veins.
- The respiratory zone is the site of gas exchange. The exchange of gases is accomplished by diffusion in thin-walled air sacs called **alveoli**.
- Adult lungs contain 300 to 500 million alveoli, with a combined internal surface area of ~75 m^2, which is approximately the size of a tennis court.
- The combined cross-sectional area of the airways in the respiratory zone is so enormous that makes the forward velocity of the gas flow **small and laminar**.
- In adults, alveoli, if damaged, have limited ability to repair themselves. Cigarette smoke, for example, can destroy alveoli and lead to concomitant decrease in alveolar surface area for gas exchange.

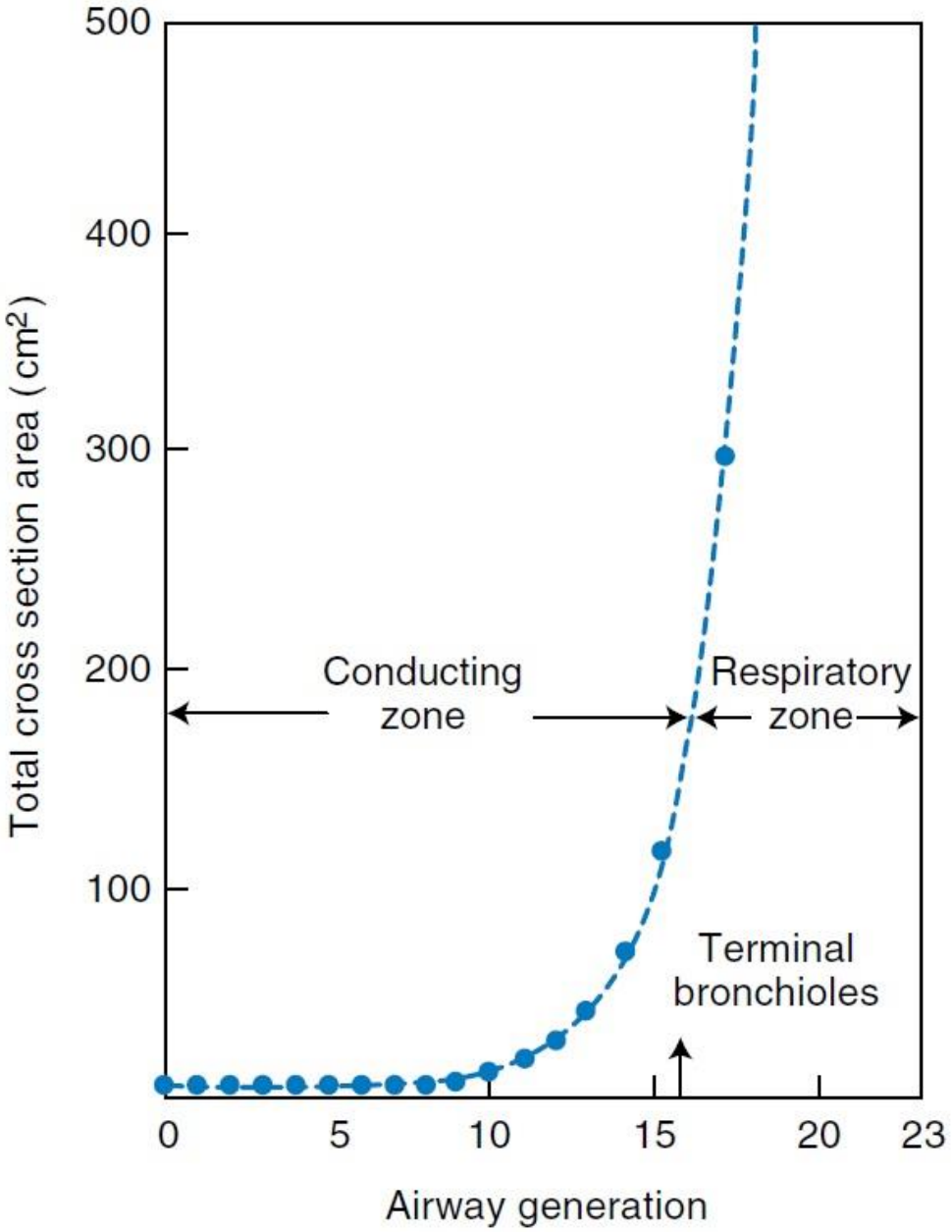


Diagram to show the extremely rapid increase in total cross-sectional area of the airways in the respiratory zone. As a result, the forward velocity of the gas during inspiration becomes very small in the region of the respiratory bronchioles, and gaseous diffusion becomes the chief mode of ventilation.

ATMOSPHERIC (BAROMETRIC) PRESSURE:

1. Air is a mixture of gases. Dry atmospheric air is approximately 79% N_2 and 21% O_2
2. Atmospheric pressure decreases as altitude increases. It is **760 mmHg** at sea level, **380 mmHg** at 18,000 feet, and **190 mmHg** at 34,000 feet
3. The total barometric pressure is the sum of the **partial pressure** of all gases (**Dalton's law**). The partial pressure of N_2 (PN_2) is 600 mmHg at sea level and PO_2 is 160 mmHg.

PULMONARY VENTILATION

Def. : The inflow and outflow of air between the atmosphere and the lung alveoli

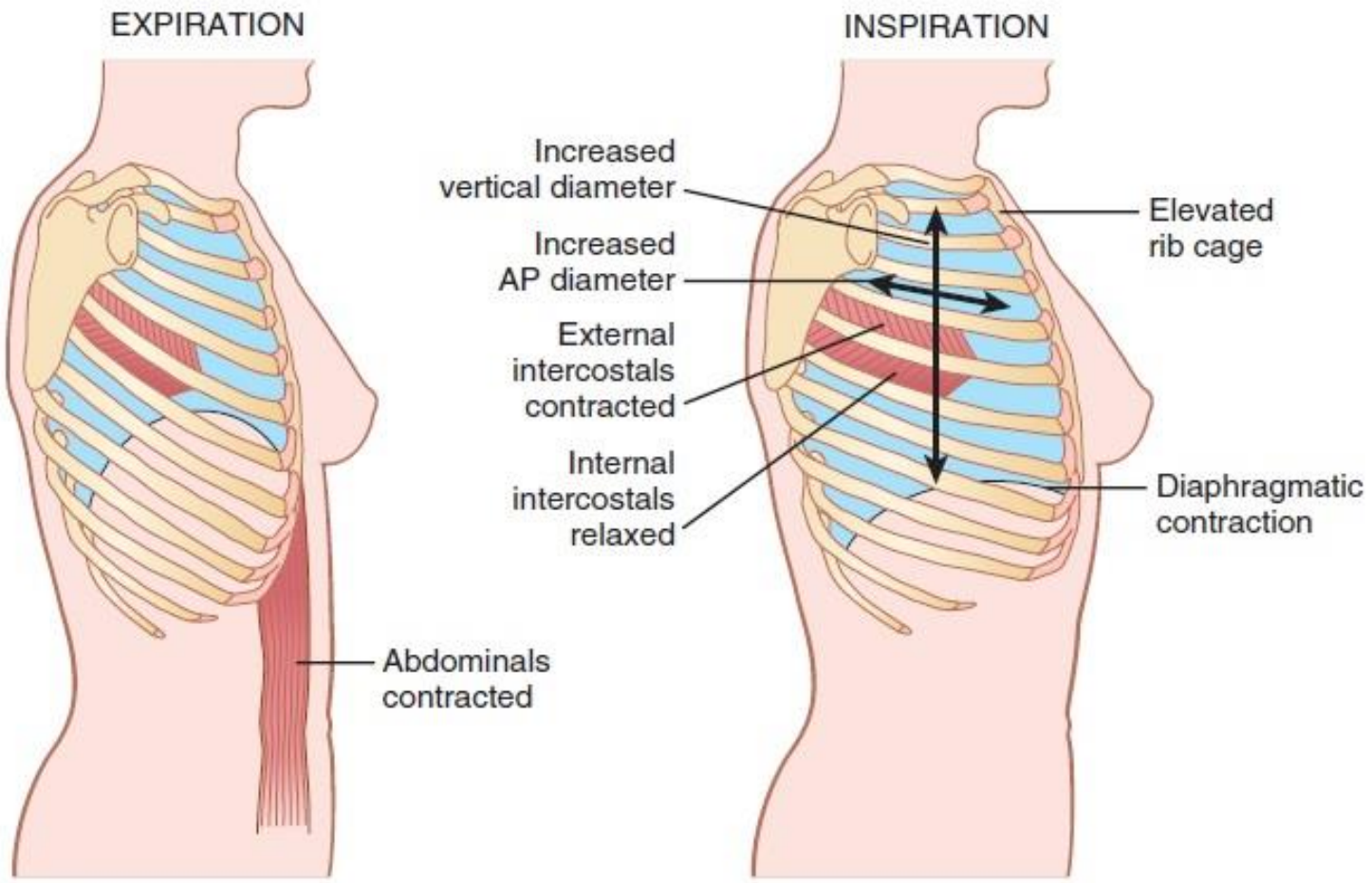
Mechanics of Pulmonary Ventilation:

1. Downward and upward movement of the **diaphragm** to increase or decrease the vertical dimension of the thorax.

Note: Obesity, pregnancy, and tight clothing around the abdominal wall can impede the effectiveness of the diaphragm in enlarging the thoracic cavity.

Damage to the phrenic nerves (C3-C5) can lead to paralysis of the diaphragm. When a phrenic nerve is damaged, that portion of the diaphragm moves up rather than down during inspiration.

2. Elevation and depression of the ribs to increase and decrease the anteroposterior diameter of the chest cavity.



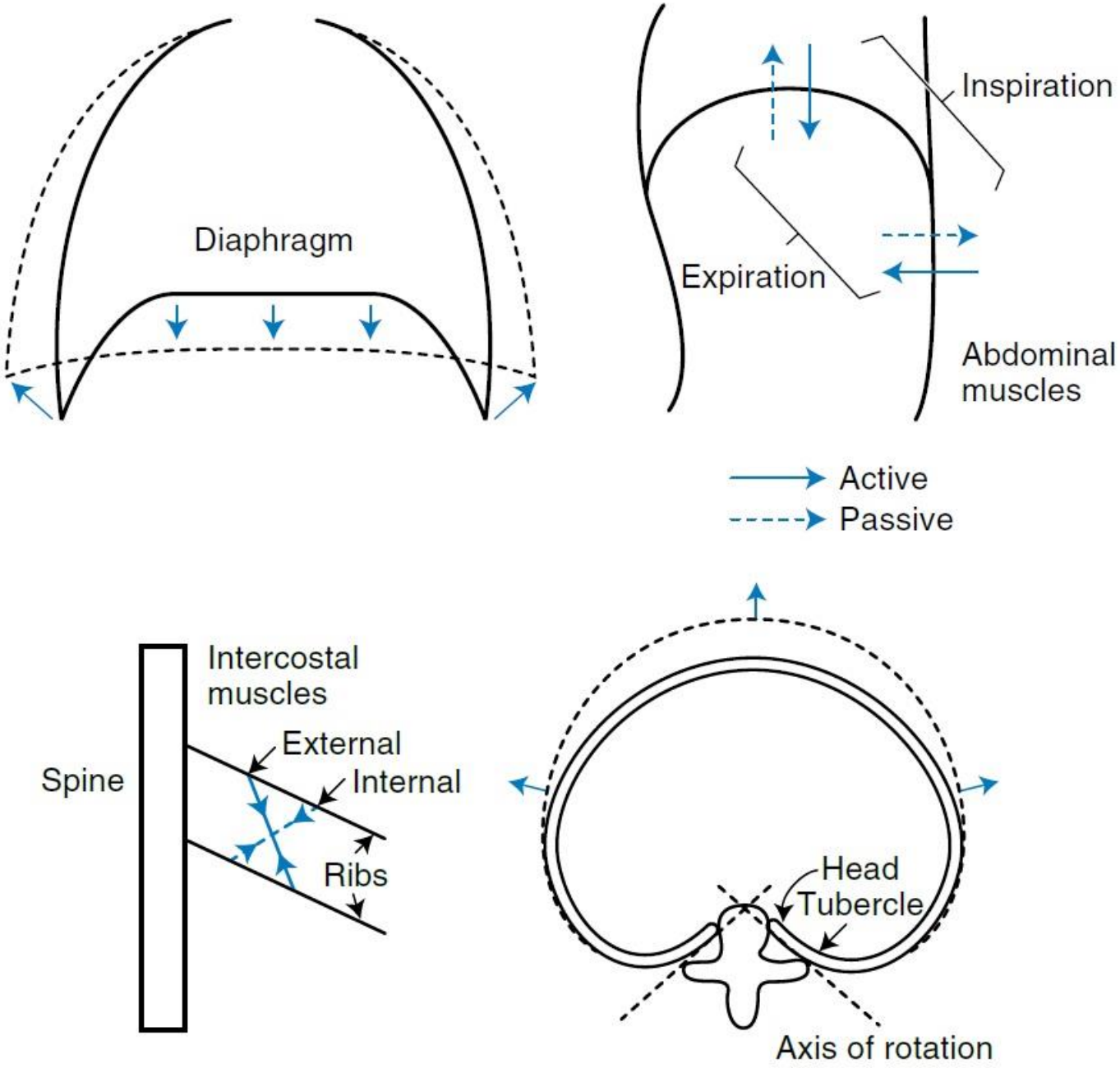
Contraction and expansion of the thoracic cage during expiration and inspiration, demonstrating diaphragmatic contraction, function of the intercostal muscles, and elevation and depression of the rib cage. AP, anteroposterior.

INSPIRATION

Inspiration is an active process, normally produced by contraction of the inspiratory muscles (negative-pressure breathing). Other than the diaphragm, Inspiratory muscles are:

1. External intercostals muscles (Bucket handle effect, most important)
2. Sternocleidomastoid muscles (lift the sternum)
3. Anterior serrati
4. Scaleni (lift the first 2 ribs)

Impaired inspiratory force (e.g. muscular dystrophy, poliomyelitis) → respiratory failure. Such patients require mechanical respirators (positive-pressure breathing).


Diaphragm
Inspiration
Expiration
Abdominal muscles
Active
Passive
Intercostal muscles
External
Internal
Spine
Ribs
Head
Tubercle
Axis of rotation

EXPIRATION

Expiration is a passive process during quiet normal breathing. Expiratory muscle contraction is required when respiration is increased during exercise or in the presence of severe respiratory disease. Expiratory muscles are:

1. Abdominal recti (pull downward on the lower ribs and compress the abdominal contents upward against the diaphragm)
2. Internal intercostals

RESPIRATORY CYCLE

Note: Pressure is taken in reference to atmospheric pressure.

Pleural pressure:

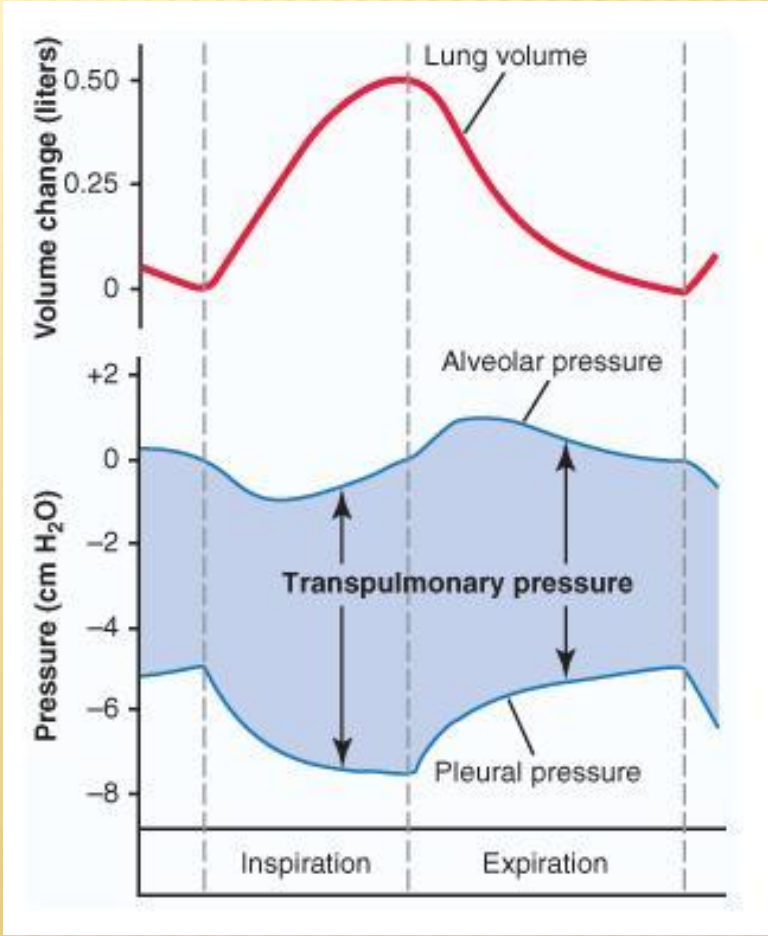
Def.: Is the pressure of the fluid in the narrow space between the lung pleura and chest wall pleura (range -5 cm H_2O to -7.5 cm H_2O). The negative pressure is because of the balanced forces generated by the **chest wall** (tends to increase lung volume, i.e. inspiratory force) and the **lungs** (tends to shrink, i.e. elastic recoil of the lung).

Alveolar pressure:

Def.: Is the pressure of the air inside the lung alveoli. It is equal to 0 cm H_2O (atmospheric) when no air is flowing into or out of the lungs.

During the respiratory cycle alveolar pressure ranges between -1 cm H_2O to +1 cm H_2O, but in patients with airway obstruction, it may be many times that.

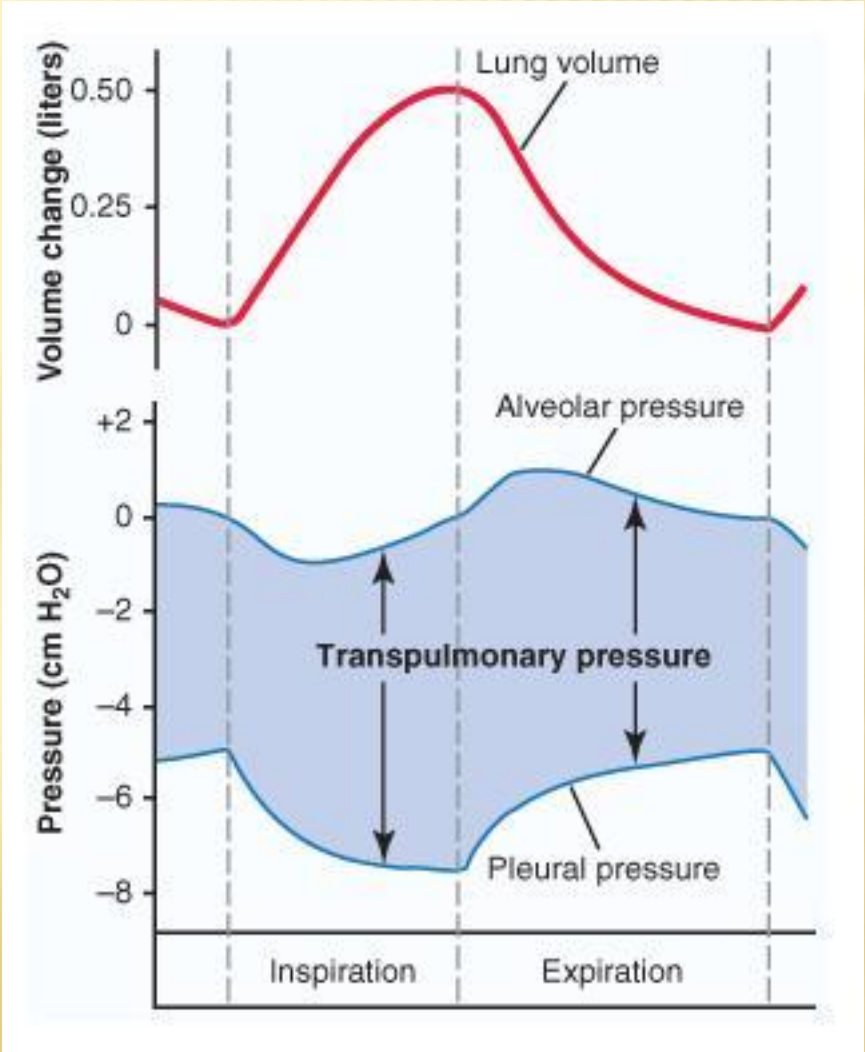
The quiet cycle is made of inspiration (2 seconds) and expiration (2-3 seconds).



RESPIRATORY CYCLE

Transpulmonary pressure (P_L):

Def.: Is the pressure difference between the alveolar pressure and the pleural pressure ($P_L = P_A - P_{PL}$). It is a measure of the elastic force (**elastance**) in the lungs that tend to collapse the lungs, i.e. the ***Recoil Pressure***. Elastance depends on the amount of elastic tissue.



TEST QUESTION:

Q. Concerning the airways of the human lung:

A. The volume of the conducting zone is about 50 ml.

B. The volume of the lung at the end of quite expiration is about 5 liters.

C. A respiratory bronchiole can be distinguished from a terminal bronchiole because the latter has alveoli in its walls.

D. On the average, there are about three branchings (i.e. generations) of the conducting airways before the first alveoli appear in their walls.

E. In the alveolar ducts, the predominant mode of gas flow is laminar rather than turbulent.