Physiology - Topic 6 - Respiratory Physiology

The Respiratory System

- Respiration supplies oxygen for cellular metabolism and removes the **carbon dioxide** produced by metabolism.
- It includes movement of air, exchange of gases across the lungs, transport in blood, and exchange between blood and tissues.
- **Ventilation** is movement of air into and out of the lungs, while **respiration** is a broader term that includes gas exchange and cellular use of oxygen.
    - A person may move air but still have poor gas exchange if alveoli are not adequately perfused.
- The respiratory system works closely with the circulation and kidneys.
- The lungs regulate **carbon dioxide** rapidly, the circulation transports respiratory gases, and the kidneys provide slower control of bicarbonate and nonvolatile acid balance.

Functional Anatomy of the Respiratory Tract

Airways, respiratory units, and blood supply

Conducting and Respiratory Portions

A. Conducting Zone

- The **conducting zone** extends from the nose to the terminal bronchioles and moves, warms, humidifies, and cleans inspired air.
- **The conducting zone** does not normally provide substantial gas exchange because its walls lack the thin alveolar exchange surface.

B. Respiratory Zone

- The **respiratory zone** includes respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.
- Its branching structure creates a large exchange area and a short diffusion distance between alveolar gas and pulmonary capillary blood.

Airway Support and Alveolar Organisation

Airway Walls and Mucociliary Defence

- **Cartilage** helps keep the trachea and larger bronchi open, while smaller bronchioles rely more on smooth-muscle tone, surrounding tissue support, and lung volume.
- Bronchiolar narrowing therefore changes with inflammation, smooth-muscle contraction, and the mechanical state of the lung.
- **Ciliated epithelium** and mucus trap and move inhaled particles toward the pharynx.

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- Alveolar macrophages remove material that reaches the gas-exchanging region, where a thick mucus layer would interfere with diffusion.

Alveolar Cells and Blood Supply

- **Type I alveolar cells** form most of the thin alveolar surface.
- Type II cells secrete surfactant and participate in repair of the alveolar epithelium after injury.
- The **pulmonary circulation** carries the whole right ventricular output to the gas-exchanging capillaries.
- The smaller bronchial circulation supplies supporting airway and lung tissues, and some bronchial venous blood returns to the pulmonary veins.

Pleural Coupling

- The visceral and parietal **pleura** enclose a thin fluid-filled potential space that allows movement while mechanically linking the lungs to the chest wall.
- Loss of this normal coupling, as in pneumothorax, alters lung expansion.

Non-Respiratory Functions of the Lungs

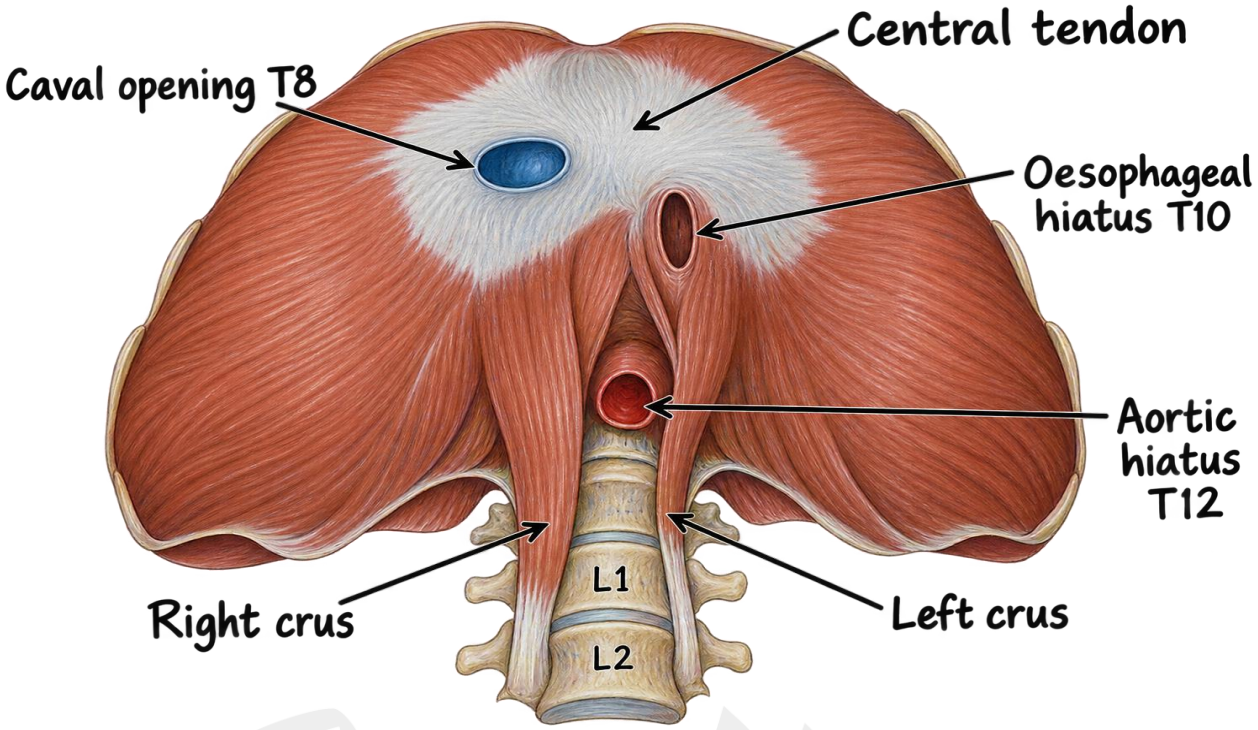
Defence, Metabolism and Other Functions

- The lungs contribute to defence through **mucociliary clearance**, cough, macrophages, and immune mechanisms.
- These defences must remove inhaled material while limiting injury to the delicate exchange surface.
- They filter some small embolic material from venous blood and act as a blood reservoir.
- This protective function has limits, and significant embolic **obstruction** can seriously impair pulmonary perfusion and right ventricular function.
- Pulmonary endothelial cells metabolise several circulating substances and contribute to conversion of **angiotensin I** to angiotensin II.
- They also influence vascular tone, coagulation, and inflammatory responses.
- In addition to its central gas-exchange function, the respiratory system enables **voice production** by supplying airflow to the larynx.
- The respiratory system supports **smell** by delivering airborne substances to olfactory receptors.
- The respiratory system also loses **water and heat** in expired air.

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Mechanics of Normal Respiration

Respiratory muscles and pressure changes



The diaphragm viewed from below, showing its central tendon, crura, and major openings

Respiratory muscles

A. Inspiration

- The **diaphragm** is the main muscle of quiet inspiration and receives motor innervation through the phrenic nerves, mainly from spinal segments C3–C5.
- Its contraction lowers the dome and increases the vertical dimension of the thorax.
- **External intercostal** activity helps expand and stabilise the rib cage.
- During increased inspiratory effort, accessory muscles such as the scalenes and sternocleidomastoids can contribute to thoracic expansion.

B. Expiration

- **Quiet expiration** is usually passive because inspiratory muscles relax and the respiratory system recoils.
- Forced expiration recruits abdominal muscles and expiratory intercostal activity to raise pleural pressure and drive air outward.
- During forced expiration, abdominal muscles push the diaphragm upwards and expiratory intercostal activity helps reduce thoracic volume.

Pressure changes and airflow

Alveolar Pressure and Airflow

- Air flows when **alveolar pressure** differs from pressure at the airway opening.

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- During spontaneous inspiration, thoracic expansion makes pleural pressure more negative, expands the alveoli, and briefly lowers alveolar pressure below atmospheric pressure.
- At the end of a quiet inspiration or expiration, airflow stops when **alveolar pressure** equals atmospheric pressure.

Intrapleural and Transpulmonary Pressures

- Pleural pressure can remain negative at these moments, so an absence of airflow does not mean that all pressures are equal.
- **Transpulmonary pressure equals alveolar pressure minus pleural pressure** and represents a distending pressure across the lung.
- At resting end-expiration, illustrative values are alveolar pressure 0 cmH_2O and pleural pressure about −5 cmH_2O relative to atmosphere.
- During a quiet inspiration, **alveolar pressure** may briefly fall to about −1 cmH_2O while pleural pressure becomes more negative.
- During quiet expiration, alveolar pressure becomes slightly positive as elastic recoil moves air out.
- The negative **pleural pressure** arises from the opposing elastic tendencies of the lung and chest wall within a closed system.
- **Negative pleural pressure** is not created by a permanent empty vacuum, and its value varies with posture, height within the thorax, and respiratory effort.

Balance at Functional Residual Capacity

- At **functional residual capacity**, the inward recoil of the lungs is balanced by the outward recoil of the chest wall.
- The combined respiratory system is therefore near its resting mechanical equilibrium at the end of a quiet expiration.

Pulmonary Surface Tension and Surfactant

Alveolar Stability and Reduction of Recoil

Surface Tension and Alveolar Stability

Origin of Surface Tension

- A liquid lining covers the alveolar surface, and its air–liquid interface produces **surface tension** that tends to reduce alveolar area.
- **Alveolar surface tension** contributes to lung recoil and would increase the pressure needed to inflate small air spaces if unopposed.

Laplace Relation and Its Limits

- For an ideal spherical air space with a single interface, Laplace's relationship is **pressure = 2 × surface tension ÷ radius**.

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- Real alveoli are interconnected and mechanically supported, so this equation explains a principle rather than describing each alveolus as an isolated bubble.

Pulmonary Surfactant

Composition and Physiological Actions

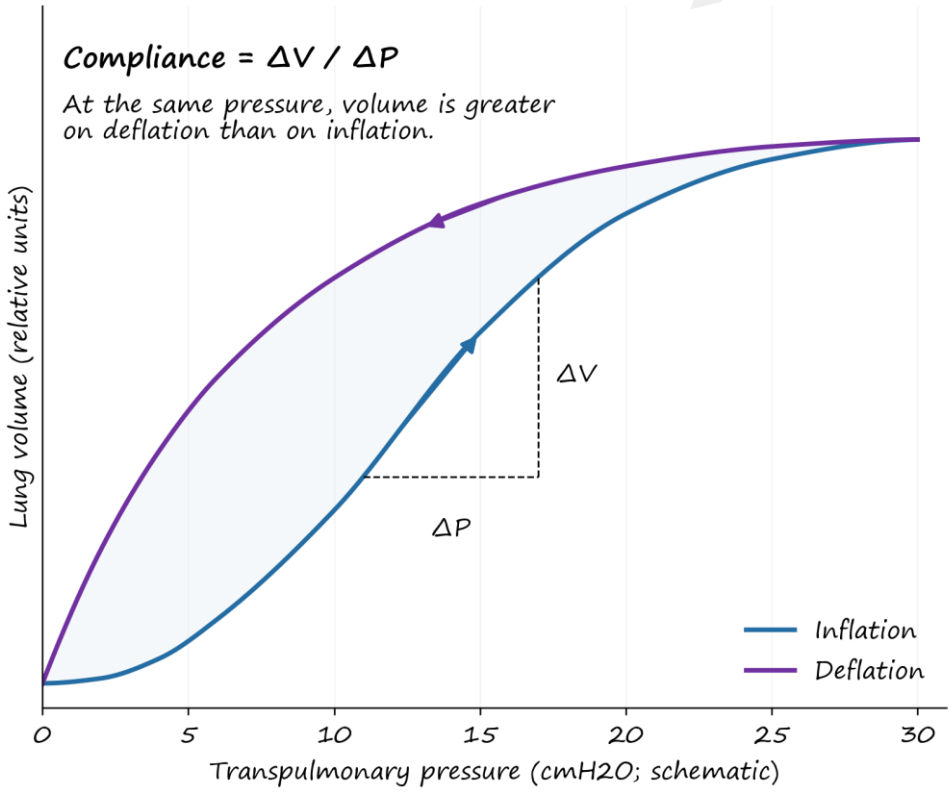
- **Surfactant** contains phospholipids, including dipalmitoylphosphatidylcholine, and specialised proteins.
- It reduces surface tension, particularly at smaller alveolar volumes, helping stabilise alveoli and reduce the work required for inflation.
- **Surfactant** also helps limit movement of fluid into alveolar air spaces and supports host defence.
- Its effect changes during the breathing cycle because molecules become more concentrated at the surface as alveoli become smaller.

Clinical Significance

- **Surfactant deficiency** in a premature newborn can cause low compliance, alveolar instability, and respiratory distress.
- Damage to the alveolar environment in adult lung injury can also impair surfactant function even when the original problem is not inadequate production.

Lung Compliance and Work of Breathing

Elastic Properties and Energy Required for Ventilation



Compliance is the slope of the pressure–volume relationship, and inflation and deflation follow different curves

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