Chapter 5 – Respiratory physiology

Introduction:
- The function of the respiratory system is the exchange of oxygen and carbon dioxide between the environment and the cells of the body.
- Air is brought into the lungs during the inspiration phase of the breathing cycle, oxygen and carbon dioxide are exchange between inspired air and pulmonary capillary blood, and the air is then expired.

Structure of the respiratory system:

Airways:
- The respiratory system consists of the lungs and the system of airways conducting air from the external environment to the lungs.
- The respiratory system is subdivided into the conducting zone and the respiratory zone:
  - Conducting zone brings air into and out of the lungs, and includes the mouth, nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles and terminal bronchioles.
  - Respiratory zone is involved in gas exchange and includes respiratory bronchioles, alveolar ducts and alveolar sacs.

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<th>Number</th>
<th>Cilia</th>
<th>Smooth Muscle</th>
<th>Cartilage</th>
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Conducting zone:
- The trachea is the main conducting airway and divides into two bronchi, one leading into each lung, which divide into two again, and again until 23 such divisions occur.
- The conducting airways are lined with mucus-secreting ciliated cells which remove inhaled particles not filtered out in the nose.
- Conducting airways contain **smooth muscle** which has both parasympathetic and sympathetic innervation:
  - Sympathetic adrenergic neurons activate $\beta_2$ receptors on bronchial smooth muscle, leading to dilatation and relaxation of the airways. They are activated by circulating epinephrine released by the adrenal medulla and by $\beta_2$ agonists such as isoproterenol.
  - Parasympathetic cholinergic neurons activate muscarinic receptors which leads to contraction and constriction of the airways.

**Respiratory zone:**
- The respiratory bronchioles are transitional structures and like the conducting airways contain smooth muscle and cilia, but are also considered part of the respiratory zone because occasionally have alveoli budding off their walls. The alveolar ducts are completely lined with alveoli but contain little smooth muscle and no cilia. The alveolar ducts terminate in alveolar sacs, which are also lined with alveoli.
- Alveolar walls are rimmed with elastic fibres and lined with epithelial cells, called type I and type II alveolar cells.
  - Type II alveolar cells synthesise pulmonary surfactant necessary to reduce surface tension of alveoli, and have regenerative capacities for both type I and type II cells.
- Alveolar macrophages fill with debris because alveoli have no cilia, and carry it to the upper airways and pharynx where it is expectorated.

**Pulmonary blood flow:**
- Pulmonary blood flow is the cardiac output of the right heart, which is ejected from the right ventricle and delivered to the lungs via the pulmonary artery. The arteries branch into smaller vessels until they reach the dense network of pulmonary capillaries surrounding the alveoli.
- Regulation of pulmonary blood flow is done by altering the resistance of the pulmonary arterioles, and these changes are mediated by local factors, predominantly oxygen.
- Bronchial circulation is the blood supply to the conducting airways and is a very small fraction of pulmonary blood flow.
Lung volumes and capacities:

Lung volumes:
- Spirometers are the tools used to measure static volumes of the lungs by recording the volume of air displaced.
- Tidal volume = normal inspiration and expiration (\(V_T\)). It has a normal value of approx. 500ml.
- Inspiratory reserve volume (IRV) = maximum amount of volume inspired \(above\) tidal volume and has a value of approx. 3000ml.
- Expiratory reserve volume (ERV) = maximum amount of volume expired \(below\) tidal volume and has a value of approx. 1200ml.
- Residual volume (RV) is the volume of gas remaining in lungs after ERV and has a value of approx. 1200ml which cannot be measured by spirometry.

Lung capacities:
- One value of lung capacity is the sum of two or more lung volumes.
- Inspiratory capacity (IC) is the tidal volume + IRV = approx. 3500ml (500ml + 3000ml).
- Functional residual capacity (FRC) is the ERV plus the residual volume = approx. 2400ml (1200ml +1200ml).
  - FRC is the volume remaining in the lungs after a normal tide volume is expired and can be thought of as the equilibrium volume of the lungs.
- Vital capacity (VC) = IC + ERV = approx. 4700ml (3500ml + 1200ml).
  - VC is the maximum volume expired after maximal inspiration.
- Total lung capacity (TLC) includes all the lung volumes. It is the VC + RV or approx. 5900ml (4900ml + 1200ml).

Dead space:
Anatomic dead space:
- Dead space is the volume of the airways and lungs that does not participate in gas exchange.
- Anatomic dead space is the volume of the conducting airways (not including respiratory bronchioles and alveoli); the total volume of which is approx. 150ml. Thus, when a tidal volume of 500ml is expired, only 350ml reaches the alveoli because 150ml occupies the anatomical dead space.
Physiologic dead space:
- The physiologic dead space is the total volume of the lungs that does not participate in gas exchange. It includes the anatomic dead space PLUS a functional dead space in the alveoli.
- Functional dead space is the ventilated alveoli that do not participate in gas exchange, the most common reason of this occurring is a mismatch of ventilation and perfusion: the ventilation/perfusion defect, where normal alveoli are not perfused by capillary blood.
- In certain pathologic conditions, the physiologic dead space can become larger than the anatomic dead space. The ratio of physiologic dead space to tidal volume provides an estimate of how much ventilation is wasted.
- The volume of physiologic dead space is estimated with the following method based on the partial pressure of CO2 (PCO2) of mixed expired air (PECO2) and the following three assumptions:
  1. All the CO2 in expired air comes from the exchange of CO2 in functioning alveoli.
  2. There is no CO2 in inspired air.
  3. The physiologic dead space does not exchange any CO2.
- If physiologic dead space is zero, then PECO2 will be equal to alveolar PCO2 (PACO2). However, if there is a dead space, the PECO2 will be diluted by dead space air and PECO2 will be less than PACO2.
- There is the issue of measuring alveolar CO2 which cannot be sampled directly. This is overcome because alveolar air equilibrates with pulmonary capillary blood. Thus, the PCO2 of systemic arterial blood (PaCO2) is equal to the PCO2 of alveolar air PACO2.
- The following equation states that the volume of dead space is the tidal volume multiplied by a fraction representing the dilution of alveolar PCO2 by dead space air.

\[
V_D = V_T \times \frac{P_{aCO_2} - P_{ECO_2}}{P_{aCO_2}}
\]

- Ventilation rates:
  - Ventilation rate is the volume of air moved into/out of the lungs per unit time. It can be expressed as minute ventilation or alveolar ventilation, the latter of which accounts for physiologic dead space.
  - Minute ventilation = \( V_T \times \) breaths/min
  - Alveolar ventilation =
\[ \dot{V}_A = (V_T - V_D) \times \text{Breaths/min} \]

Where

\[ \dot{V}_A = \text{Alveolar ventilation (mL/min)} \]
\[ V_T = \text{Tidal volume (mL)} \]
\[ V_D = \text{Physiologic dead space (mL)} \]

**SAMPLE PROBLEM.**

A man who has a tidal volume of 550 mL is breathing at a rate of 14 breaths/min. The Pco₂ in his arterial blood is 40 mm Hg, and the Pco₂ in his expired air is 30 mm Hg. What is his minute ventilation? What is his alveolar ventilation? What percentage of each tidal volume reaches functioning alveoli? What percentage of each tidal volume is dead space?