

Title : Physiology of Respiratory System

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I. Respiratory Tract

A. The principal organs of the respiratory system include the nose, pharynx, larynx, trachea bronchi, and lungs. Within the lungs the main bronchi branch into 22 generations.

1. Anatomic Division

- a. *The upper respiratory tract* - the airways from the nose through the larynx.
- b. *The lower respiratory tract* - the airways from the trachea through the lungs.

2. Physiologic Division

- a. *The conducting zone* – the airways that serve for airflow, mainly from the nostrils through the bronchioles (to the 16th generations – terminal bronchioles).
- b. *The transitional and respiratory zones* - the respiratory bronchioles, alveolar ducts and alveoli.

3. Conducting Zone – Functions:

- a. Air distribution to the gas exchange surface.
- b. Warming and humidifying the air.
- c. Serving as a part of body defence system.
- d. Preventing the alveolar oxygen and carbon dioxide partial pressures from extreme changing.

B. Air Flow and Airway Resistance

1. *The volume of air that enters or leaves the alveoli per time unit is directly proportionate to the pressure difference and inversely proportionate to the airway resistance.*

2. The airway resistance is directly proportionate to the length of the airway and the magnitude of interactions between the flowing gas molecules, and *it is inversely proportionate to r^4 or r^5* (r - airway radius).
3. When the breathing frequency is 15 times per minute, the airway resistance provides 28% of the total resistance to ventilation.
4. Many factors, such as lung expansion, stimulation of muscarinic or beta-adrenergic receptors modify the airway diameter and, consequently, the airway resistance.
 - a. *Stimulation of muscarinic receptors (cholinergic stimulation) causes bronchoconstriction.*
 - b. *Stimulation of beta-adrenergic receptors causes airway dilation.*
 - c. *During inspiration the airways widen and the airway resistance decreases. Conversely, during expiration the airways narrow and the airway resistance increases.*

C. Alveoli and Alveolar Gas Exchange

1. An alveolus is lined with a continuous and single layer of epithelial cells. Type I cells (squamous cells) are primary lining cells, while type II cells produce and secrete surfactant. Alveolar macrophages (dust cells) present in the alveoli are the last element of defence system against inhaled matter.
2. Each alveolus is surrounded with a network of capillaries.
3. Gas diffusion occurs through the *alveolar - capillary membrane* of 0,2 – 0,6 μm . The alveolar-capillary membrane is composed of several layers, such as: *a fluid layer containing surfactant, the alveolar epithelium and its basement membrane, an interstitial space, the basement membrane of capillary endothelium, and endothelial cells.*
4. Total area of the alveolar walls in contact with capillaries, which is 70 square meters, can compensate for high metabolic rates and oxygen needs.
5. The efficiency of gas exchange through the alveolar -capillary membrane is affected by several factors including *concentration gradients of the gases, solubility of the gases, membrane thickness, membrane area, and ventilation-perfusion coupling.*

D. Minute Ventilation and Alveolar Ventilation

1. Minute ventilation (minute volume) is the total volume of air that enters the lungs each minute.

$$\text{minute ventilation (ml/min)} = \text{breathing frequency (breaths/min)} \times \text{tidal volume (ml)}$$

2. Since gas exchange does not occur in the conducting zone of the airways, its volume is called *anatomic dead space* (2 ml/kg ideal body weight) – about 150 ml.

3. Alveolar ventilation is the volume of *fresh air* that enters the alveoli each minute.

$$\text{alveolar ventilation (ml/min)} = [\text{tidal volume (ml)} - \text{anatomic dead space volume (ml)}] \times \text{breathing frequency (breaths/min)}.$$

4. *The more shallow and rapid breathing the worse the alveolar ventilation.*

5. Determination of alveolar ventilation is the most direct relevant measurement of the body's ability to get oxygen to the tissues.

6. *The term dead space refers to the volume of air in the lungs that cannot exchange gases with blood.* Physiologic (total) dead space is the sum of the anatomic dead space and any dead space that may exist in the lungs (alveolar dead space means the volume of ventilated but not perfused alveoli). In healthy subjects, the anatomic and physiologic dead spaces are equal.

II. Mechanics of Pulmonary Ventilation

A. Respiratory Muscles

1. Inspiratory muscles include *the diaphragm, external intercostal muscles, and the accessory muscles (neck and chest muscles).*

2. Expiratory muscles include *the internal intercostal muscles and the abdominal muscles.*

B. Lung Pressures and their Changes during a Breathing Cycle

1. *The pleural (intrapleural) pressure (P_{pl}) is the pressure of the fluid in the pleural space.*
2. *The alveolar pressure (P_A) is the pressure of the air inside the alveoli.*
3. *The transpulmonary (transpulmonic) pressure (P_{TP}) is the difference between the alveolar and the pleural pressure ($P_{TP} = P_A - P_{pl}$).*

C. Inspiration - A Sequence of Events:

1. Contraction of the inspiratory muscles.
2. Expansion of the thoracic cavity.
3. A decrease in the intrapleural pressure.
4. An increase in the transpulmonic pressure.
5. Lungs' expansion. (Another force that expands the lungs is warming of the inhaled air).
6. A drop of the alveolar pressure below the atmospheric level.
7. Generation of pressure gradient between the nose (mouth) and alveoli.
8. Air movement into the lungs.

D. Expiration

1. *Quiet expiration occurs due to relaxation of the diaphragm and external intercostal muscles that, because of the elastic recoil, returns lungs to their previous position. Since the alveolar pressure is above the atmospheric pressure, the air leaves the lungs.*
2. The expiratory muscles are used to force a deeper expiration.

E. Resistance to Ventilation

During inspiration the inspiratory muscles contract to expand the lungs against their elastic forces and to overcome the airway resistance, and viscous resistance. *Tissue elastic forces (1/3) and the surface tension in the alveoli (2/3) produce the elastic forces of the lungs.*

F. Lung Compliance

1. *Lung compliance is defined as a change in lung volume that occurs with the change in intrapleural (or transpulmonic) pressure.*
1. Lung compliance can be measured under either static, or dynamic conditions.
2. *Lung compliance is decreased in interstitial pulmonary fibrosis, pulmonary congestion, pulmonary oedema, pneumonia, and it is increased in emphysema.*

E. Alveolar Surface Tension and Surfactant

1. The surface of alveolar epithelium is covered with a thin film of fluid. *Surface tension* created at the gas – liquid interface *tends to reduce the surface area and volume of the alveoli (La Place`s law).*
2. *Surfactant reduces surface tension* within the alveoli and has many physiologic effects.
3. Surfactant damage or deficiency (often present in premature infants) causes a great difficulty in breathing.

III. Pulmonary Circulation

The pressures in the pulmonary circulation are remarkably low due to:

- the enormous number of small muscular pulmonary arteries,
- the enormous pulmonary capillary bed,
- low vascular resistance of the pulmonary vessels

IV. Gas Transport and Systemic Gas Exchange

V. Ventilation-Perfusion Coupling

A. Distribution of Pulmonary Ventilation

In the upright position, better ventilation is found at the bottom of the lungs than at the apex.

B. Distribution of Pulmonary Blood Flow

In the upright position, better perfusion is found at the lower portions of the lungs than at the upper ones.

C. Ventilation/Perfusion Ratio

- 1. Minute alveolar ventilation /minute perfusion ratio (V_A/Q) is the major determinant of the composition of blood leaving the capillaries surrounding the alveoli.*
- 2. Reduced ventilation/perfusion ratio results from inadequate ventilation in relation to perfusion, that produces the physiologic shunt (venous admixture) found at the bottom of the lungs. The anatomic shunts include bronchopulmonary venous anastomoses and intracardiac thebesian veins. Both shunts decrease arterial PO_2 by 5%.
*Pathologic conditions producing reduced ventilation/perfusion ratio include narrowing or obstruction of the airways (asthma, bronchitis, emphysema, tumor).**
- 3. Increased ventilation/perfusion ratio results from inadequate perfusion in relation to ventilation, that may produce the alveolar dead space at the top of the lungs.
*Pathologic conditions producing increased ventilation/perfusion ratio include compression (tumor, fluid, gas) or obstruction (embolism) of the pulmonary artery and/or its branches, loss of capillary bed (emphysema), and shock.**

VI. Control of Respiration

A. Automatic Control of Breathing - Control Centers in the Brain Stem

1. Control Centers in Medulla Oblongata

- a.** Breathing relies on repetitive stimulation from the brain stem.
- b.** Two types of respiratory neurons are present in the medulla oblongata: *inspiratory (I) neurons*, which discharge during inhalation, and *expiratory (E) neurons*, which discharge during forced (not quiet) expiration.
- c.** These neurons create the respiratory center with two groups of neurons:
 - The dorsal respiratory group (DRG) - *inspiratory center*, which is made up of type I neurons that stimulate the inspiratory muscles. *It is primarily responsible for the basic rhythm of breathing*
 - The ventral respiratory group (VRG) - *expiratory center*, which contributes to both inspiration and expiration (*during increased ventilation*).

2. Control Centers in the Pons

- a.** *The pneumotaxic center* is involved in regulation of depth and rate breathing.
- b.** The role of the apneustic center is still hypothetical.

B. Stimuli Affecting the Respiratory Center

- 1.** The brainstem respiratory center receives input from the limbic system and hypothalamus.
- 2.** The rate and depth of breathing are altered dependently on metabolic need.
 - a.** *Central chemoreceptors (in the medulla) are stimulated by an increase in hydrogen ions concentration in the cerebrospinal fluid and tissue fluid of the brain, and, indirectly, by increased P_{CO_2} in the arterial blood and cerebrospinal fluid.*
 - b.** *Peripheral chemoreceptors (in the carotid and aortic bodies) are sensitive to the changes in arterial oxygen, carbon dioxide, and pH levels.*
- 3.** *The vagal fibres* transmit sensory input from receptors present in the airways.
 - a.** Stimulation of *slowly adapting receptors (SARs)* by steady lung inflation triggers the *inflation (Hering- Breuer) reflex that stops inspiration.*

- b. Stimulation of *rapidly adapting receptors (RARs)* in the airways, may cause *coughing, increased mucus secretion, or bronchoconstriction.*
- 4. The respiratory center is also affected by afferents from proprioceptors and baroreceptors.

C. Voluntary Control

1. Voluntary control over pulmonary ventilation originates in the *motor cortex* of cerebral frontal lobe. The impulses are transmitted down the corticospinal tracts to the respiratory neurons in the spinal cord, bypassing the brainstem respiratory centers.
2. There are limits to voluntary control.

VII. Aviation, Space and Deep-sea Diving Physiology.