# Pathophysiology of respiratory system/high school (nurse)

***Wording of the question***: Definition, division, terminology, etiopathogenesis. External respiration (respiration, ventilation, mechanical respiration, diffusion, perfusion), internal respiration. Clinical picture of hypoxia, hypocapnia, hypercapnia, dyspnea, orthopnea, cyanosis. Disorders of the internal environment – respiratory alkalosis, respiratory acidosis.

- The respiratory system serves as a gas exchanger between the surrounding environment and the internal environment of the organism.
- Respiration is the process by which gases are exchanged. Under this term we include **ventilation** (external breathing) and **respiration** (internal breathing).

## Upper respiratory tract

**Nasal cavity** = cavum nasi.

- It is used to heat the breathing mixture.
- It serves to purify the inhaled mixture.
- Sensory cells of smell.
- Irritation of the olfactory cells causes sneezing.
- The epithelium produces mucus, in which small particles of dirt (e.g. dust) are trapped.
- Reflex respiratory arrest is induced when an irritating substance is inhaled.

**Oral cavity** = cavum oris.

- Used for straining and obstruction of the nasal cavity.

**Pharynx**

- 3 parts.
- Air goes to the lungs and food to the esophagus.

**Larynx**

- Laryngeal flap (epiglottis) preventing food from entering the respiratory tract.
- Vocal cords enabling the production of speech.

## Lower respiratory tract

- When the vagus nerve is irritated, a defensive reflex is triggered - coughing.

**Windpipe** = trachea.

- Made up of cartilage.
- Ciliated epithelium that allows mucus to move towards the oral cavity.

**Bronchi**

- Right and left bronchus, the left forms a sharper angle with the trachea.
- Ciliated epithelium.
- Smooth muscle influenced by the vegetative nervous system (parasympathetic causes contraction, sympathetic dilation).
- They branch further into small bronchi.

**Lungs** = pulmones.

- Paired organ formed by lung cells (alveoli).
- Instead of gas exchange.
- The developed alveoli are maintained by surfactant.

## Ventilation

- Cyclic action during which inhalation and exhalation are repeated.

**A breath**

- Inspirium, active storyline.
- The main respiratory muscles are the diaphragm and intercostal muscles, the auxiliary respiratory muscles are the pectoral, subclavian and head nodular muscles.

    - During inspiration, the diaphragm descends, the intercostal muscles turn the ribs to the sides and forward.

The volume of one breath is calculated by the formula... 5 - 7 ml / kg. (a person weighing 84 kg will have an optimal tidal volume between 420 and 588 ml of inhaled atmospheric mixture)

- Inhaled volume approx. 500 ml.
- The dead space has a volume of approx. 150 ml (a space where gas exchange does not occur).
- The simultaneous movement of the chest and lungs allows negative pressure in the interpleural space.

**Exhale**

- Exspirium, plot passive,
    - the abdominal organs push the diaphragm back up, the inherent elasticity of the chest returns the ribs to their original position,

→ at least muscularly demanding. The diaphragm and intercostal muscles slacken, the chest falls under its own weight, the diaphragm arches back into the chest. The volume decreases, the excess pressure in the lungs is equalized with respect to the external environment by exhaling until the pressures are equalized again.

- **By ventilation** we mean the transport of oxygen from the external environment to the alveoli and the transport of $CO_2$ in the opposite direction. It has the highest reserve of all body functions.
- **Breathing mechanics** → breathing is ensured by respiratory movements, carried out by the activity of the striated respiratory muscles. It takes place in a rhythmic cycle of inhalation - exhalation - a very short pause. During calm breathing, active muscle activity is significant only during inhalation. It claims only 5% of the total oxygen consumption in the organism.
    - Diaphragm – it is controlled by nerves from the area of the first to fourth vertebrae of the cervical spine, its spasmodic contractions cause hiccups, which is actually a deformed exhalation.
    - The intercostal muscles are supplied by nerves from the thoracic spine.
    - Difficult breathing or greatly deepened breathing also involves the auxiliary respiratory muscles in the respiratory activity. For inhalation, these are the muscles of the neck, arm girdle and back, for exhalation, the muscles of the abdominal wall. Exhalation becomes active. Oxygen consumption in the respiratory muscles rises to 40% of the total oxygen consumption in the body. Physical effort is manifested by finding a suitable position - sitting and leaning, sweating, tachycardia, gradual exhaustion and secondary respiratory insufficiency.
- Diffusion – the passage of inhaled and exhaled gases from the alveoli to the pulmonary capillaries and vice versa through the alveocapillary membrane. Under normal conditions, it is fast and effective. Diffusion of oxygen is significantly worsened in case of pulmonary edema in left-sided heart failure, in case of moist lung, e.g. after drowning, in case of pulmonary fibrosis.
- Perfusion – blood flow through the pulmonary capillary bed. It determines the inflow and outflow of blood gases and the flushing of inhaled anesthetics from the lungs. Perfusion must be in reasonable balance with ventilation so that there is no disadvantageous disparity on both sides of the alveocapillary membrane. Typical clinical examples of a critical disparity are:
    - DC obstruction preventing ventilation. Oxygen does not reach the exchange surface. Even if the perfusion is sufficient, the patient is exposed to a lack of oxygen.
    - Pulmonary artery embolism. The patient ventilates even with increased effort, oxygen is brought to the alveoli. However, the blood flow is stopped by the wedged embolus and oxygen cannot be transported to the tissues.
- Distribution – distribution of the inhaled mixture in the lungs. Even in a physiological state, it is not exactly uniform. In an inappropriate operating position or during artificial respiration, the distribution is very uneven, parts of the lungs are ventilated very poorly. When lying flat on the back, the lower lobes in the area along the spine are the worst ventilated. That is why changes in position and occasional deep breaths are extremely important. Otherwise, atelectasis and bronchopneumonia easily occur in poorly ventilated areas. Distribution takes place most advantageously in the last third of inhalation. Therefore, slower frequencies and a short delay in the last third of artificial inspiration are chosen for UPV.

**Basic concepts:**

- Eupnoea = normal, resting breathing.
- Tachypnea = rapid breathing.
- Hyperpnea = deepened breathing.
- Apnea = no breathing.
- Ortopnea = labored breathing with the involvement of auxiliary respiratory muscles.
- Dyspnoea = shortness of breath.
- Vital lung capacity /vc/ = expiratory volume + reserve expiratory volume + reserve inspiratory volume.
- Functional residual capacity = residual volume + inspiratory reserve volume.
- Normoxemia = normal concentration of $O_2$ in the blood.
- Hypoxemia = lack of $O_2$ in the blood.

- Normoxia = normal value of $O_2$ in tissues.
- Hypoxia = lack of $O_2$ in the tissues.
- Hyperoxia = excess $O_2$ in the tissues.
- Normocapnia = normal concentration of $CO_2$ in the blood.
- Hypocapnia = lack of $CO_2$ in the blood.
- Hypercapnia = excess $CO_2$ in the blood.

# Biochemistry of respiration

We normally breathe atmospheric air at a normal atmospheric pressure of 0.1 MPa with the following composition: oxygen 21%, nitrogen 78%, rare gases 1%, carbon dioxide, water vapor. In anesthesiology, during UPV, in a hyperbaric chamber, another mixture can be introduced into the lungs and under changed pressure conditions.

- When evaluating blood gases, their quantity is not normally used in clinical practice, but rather their partial pressures ($pO_2$, $pCO_2$).

## Oxygen

- Consumption is related to the metabolic demands of the organism (different organs or tissues have different relative consumption).
    - The more active an organ is, the greater its need, and thus it can be damaged more or earlier due to lack of it.
- The largest amount is bound to hemoglobin → oxyhemoglobin; indicates the transport capacity of the blood.
    - A minimal amount is transported in the plasma.
    - It moves into cells and enters enzymatic metabolic cellular events. If a person inhales pure oxygen, the amount of physically dissolved oxygen increases, but the amount bound to hemoglobin does not increase, because even when breathing air, all hemoglobin is already occupied by oxygen.
    - If, in addition, the oxygen pressure is increased above atmospheric (e.g. hyperbaric chambers), the amount of dissolved oxygen in the plasma will increase many times.

## Carbon dioxide

- It is formed during metabolism.
- It is transported to the lungs to be exhaled.
    - Freely dissolved physically in the plasma only in a minimal amount.
    - Binding to hemoglobin as carboxyhemoglobin.
    - Most of it is chemically bound in the blood as bicarbonate – $HCO_3^-$.

### Values of ASTRUP

- When breathing atmospheric air with 21% oxygen, i.e. with an inspiratory fraction of oxygen $FIO_2$ = 0.21 at a pressure of 0.1 MPa and under physiological conditions of ventilation and perfusion, a person reaches the following values:
    - **Arterial blood**:
        - $paO_2$ =13,3 kPa,
        - $paCO_2$ = 5,3 kPa,

→ must be assessed individually!!!

- Values indicative of insufficient blood gas exchange:
    - $paO_2$ lower than 8,0 kPa,
    - $paCO_2$ higher than 8,0 kPa.

# Breath control

- The respiratory center is located in the medulla oblongata, the pneumotaxic center is in the brainstem.
- Free control of breathing is provided by the cerebral cortex.
- Emotional influences are transmitted from the centers of the vegetative nervous system - the hypothalamus and the limbic system.
- Deflation and inflation receptors of the lungs → vagus nerve → respiratory center,
    - ensuring the alternation of inhalation and exhalation = self-regulating Hering-Breuer respiratory reflex.
- Peripheral chemoreceptors in the arch of the aorta and in the bifurcation of the carotid bodies and central

chemoreceptors in the respiratory center responding to the level of $CO_2$.

# Hypoxia

Hypoxia is a term expressing a lack of oxygen in the cells.

## Division by cause and effect

- Hypoxic – the cause is a lack of oxygen in the atmosphere → little oxygen passes into the blood → low $pO_2$ in the arterial blood.
    - Mountain sickness, onem. of the lungs leads to systemic hypoxia.
- Anemic (transport) – there is a lack of free hemoglobin in the blood → normal $pO_2$ in arterial blood, reduced value of total $O_2$ in arterial blood ($CaO_2$).
    - Anemia, $CO_2$ poisoning causes systemic hypoxia.
- Circulatory (stagnant) – small blood flow through tissues and maximum oxygen consumption → normal $pO_2$ in arterial blood.
    - Heart failure or shock → general hypoxia.
    - Thrombosis, embolism, trauma → local hypoxia.
- Histotoxis (cytotoxic) – the use of oxygen in the cells is impaired, although the supply of $O_2$ is sufficient, the cells cannot use it for the formation of ATP → high $pO_2$.
    - Cyanide poisoning, cyankali.
- Hypermetabolic – tissue demands are so high that normal $O_2$ supply is not enough.
    - Thyrotoxic crisis, sepsis.

## Clinical picture

Lack of oxygen → conversion of aerobic metabolism to anaerobic → accumulation of acids → acidosis,

→ lack of energy caused by inefficient use of ATP → limitation of cell function → irreversible changes.

- Rapid fatigue, drowsiness, unconsciousness, convulsions.
- Depression, confusion, restlessness, hallucinations.
- Bradycardia or tachycardia, cardiac arrest.
- Initially hypertension then hypotension.
- Hyperventilation, tachypnea, gradually gasping breaths.
- Cyanosis – when the mean hemoglobin concentration drops below 0.7 mmol/l.

The course is different according to the severity of hypoxia and the speed of its onset.

- In general anesthesia, the symptoms of hypoxia are extremely poor, there is no defensive activation of the organism. The same inconspicuous, masked course is seen in critically ill patients in resuscitation care on ventilators and in neurologically impaired patients. The only symptoms are slight restlessness, inconsistency with the ventilator, possibly. cyanosis, bradycardia, circulatory arrest.

Hypoxia is an immediate life-threatening condition. Even subacute hypoxia can be fatal, especially if it goes unnoticed for a long time. It may not be accompanied by cyanosis, its manifestations may be poor. Restlessness is a paradoxical manifestation of hypoxia. If there is peace restless, hypoxia must be ruled out before calming or disciplining him.

# Hyperoxie

A condition characterized by a prolonged excess of oxygen in the blood. A $pO_2$ in arterial blood higher than 33 kPa, lasting several hours, is considered dangerous. → oxygen toxicity

# Hyperkapnie

= increased carbon dioxide content in the blood.

- Hypoventilation → increased amount of $CO_2$ → vasodilation, respiratory acidosis.
- Clinical picture: Increase in intracranial pressure, blood pressure, headache, redness, or sweating, later delirium appears, respiratory depression, unconsciousness, cardiac arrest.
    - In anesthesia and in resuscitation care, the symptoms are poor and can be limited to a progressive rise in blood pressure with a very hard pulse and incompatibility with the ventilator.

# Hypokapnie

= Reduced carbon dioxide content in the blood.

- It is a result of hyperventilation. It is easily created if it is pac. ventilated with excessive volumes during anesthesia or resuscitation care.
- Clinical picture: Pallor, hypotension.
    - Subjective tingling in the hands and around the mouth, muscle stiffness, later tetany with ``birth hand *appears, muscle twitches, general convulsions, unconsciousness. The condition can cause cardiac arrest.*
    - A $pCO_2$ value in arterial blood below 2.6 kPa is considered a dangerous level.

# Dyspnea

- It expresses the subjective feeling of labored breathing, experienced very unpleasantly by the patient, accompanied by a feeling of lack of air.
- A patient on a ventilator may also feel short of breath if the mode is not set, if there is insufficient supply of oxygen, etc.

# Ortopnoe

- It expresses an objectively visible image of labored breathing. The patient engages the auxiliary respiratory muscles, the snoring can be seen. He looks for a sitting position with arms resting, in a forward bend, puts DK in a lowered position.

# Cyanosis

- It expresses the appearance of the patient with the coloring of the mucous membranes and skin in a cherry to blue-gray color.
- In most cases, cyanosis indicates a lack of oxygen.
- Hemoglobin also acquires a blue color when combined with nitrites or sulfur compounds. A significantly smaller amount of hemoglobin that has been changed in this way is sufficient for the intense blue shade.

# Respiratory alkalosis

- The essence is a decrease in $pCO_2$ → HYPOKAPNIA
- Causes:
    1. Irritation of the respiratory center – psychogenic influences, hypoxemia in lung disease, VVV with right-left shunts, stay at high altitudes.
    2. Inappropriately set UPV - most often during hyperventilation.
- Clinical picture:
    - Hyperventilation → hypocapnia → vasoconstriction of cerebral vessels → possible brain ischemia → further stimulation of hyperventilation.
    - When $pCO_2$ drops below approx. 3 kPa, brain perfusion is significantly reduced!
- ABR investigation:
    - alkalosis - increased pH,
    - decrease in bicarbonate,
    - reduction of Base Excess (BE),
        - Renal compensation.

# Respiratory acidosis

- The cause is the accumulation of $CO_2$ in the body → it occurs in conditions where there is hypoventilation, limiting gas exchange in the lungs.
    - hypercapnia up to approx. 8 kPa = stimulation of the respiratory center,
    - hypercapnia above 8kPa = respiratory center depression, hypoxemia is the only stimulus to maintain ventilation. Cave oxygen therapy without UPV in these patients!!!
- Causes:
    1. Alveolar hypoventilation – shock lung, acute respiratory insufficiency, pneumothorax, etc.
    2. Inhaling a mixture of gases with a higher $CO_2$ content.
        - Exhaustion of soda lime in the absorber of the anesthesia machine.

- Clinical picture:
  - Cyanosis, shortness of breath, tachypnea, restlessness, disorders of consciousness, heart rhythm disorders.
  - ASTRUP: lower pH, higher $pCO_2$, decrease in BE.
    - Renal compensation → higher $HCO_3$, BE rises, $pCO_2$ does not change.

# Links

## Related articles

- Lung volumes
- Mechanics of breathing
- Lung compliance
- Pulmonary ventilation - perfusion ratio
- Binding of oxygen to hemoglobin
- O2 transport by blood
- Transport of CO2 by blood
- Chemical regulation of respiration
- Nervous regulation of breathing
- Anoxia
- Asphyxia
- Acute mountain sickness
- Caisson disease
- Hypoxia (in detail)

## References


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