PHYSIOLOGY OF RESPIRATION

Respiration includes 2 processes:

1) External respiration – is the uptake of O_2 and excretion of CO_2 in the lungs
2) Internal respiration – means the O_2 and CO_2 exchange between the cells and capillary blood

The quality of these respiration processes depends on:

a) pulmonary ventilation – it means the inflow and outflow of air between the atmosphere and the lung alveoli
b) diffusion of oxygen and CO_2 between the alveoli and the blood
c) perfusion – of lungs with blood
d) transport of O_2 and CO_2 in the blood
e) regulation of respiration

Nonrespiratory functions:
- in voice production
- protective reflexes (apnoea, laryngospasm)
- defensive reflexes (cough, sneeze)
- in thermoregulation

STRUCTURE OF THE RESPIRATORY TRACT

Upper airways - nose,nasopharynynx - borderline - larynx
Lower airways - trachea, bronchi, bronchioles.
The airways divide 23 times to 23 generations between the trachea and:

Alveoli - 300 milion - total surface area 70 m^2 lined pneumocytes
- type I -flat cells
- type II - producers of the surfactant
- lymphocytes, plasma cells, alveolar macrophages, mast cells....

Innervation: Smooth muscles innervated by **autonomic nervous system:**
- **parasympathetic** - muscarinic - bronchoconstriction
- **sympathetic** - $beta_2$ - receptors – bronchodilation - mainly to adrenalin
- **noncholinergic nonadrenergic** innervation - VIP

MECHANICS OF VENTILATION

Inspiration - an active process - contraction of the inspiratory muscles:
- **Diaphragm** - accounts for 60-75% of the tidal volume
- **External intercostal muscles**
- **Auxiliary**-accessory-inspiratory muscles: Scalene and sternocleidomasoid m.m.

Expiration - quiet breathing - passive process - given by elasticity of the chest and lungs
- forced expirium - active process – expiratory muscles:
  - Internal intercostal m.m.
  - Muscles of the anterior abdominal wall

Innervation: Motoneurons: Diaphragm – n.n. phrenici (C_3-C_5)
Others–lower segments o the spinal cord

Pulmonary ventilation

- the volume of the air inspired and expired per time unit
- mostly expressed as minute ventilation MV = V_T x f (6-8 l/min)

Increase in alveolar ventilation over the requirements of the metabolism –
→ hyperventilation (decrease in P_ACO_2 and increase in P_AO_2, the result -
– hypocapnia
- it means – hyperventilation causes respiratory alcalosis

an opposite situation – hypoventilation – hypercapnia – respiratory acidosis

Maximum voluntary ventilation MVV 120 – 180 l/min

Terminology

eupnoe – normal quiet breathing
tachypnoe – breathing at higher frequency
bradypnoe – breathing with lower frequency
hyperpnoe – deeper br.
dyspnoe – laborious br.
ortopnoe – using auxilliary muscles
apnoe - cease of breathing

Pulmonary ventilation consists of:
1) alveolar ventilation
2) ventilation of dead space

Alveolar ventilation

- is the amount of air reaching the alveoli

- if the frequency of breathing is 12/min and V_T is 500 ml, than minute ventilation is 6 litres.
- If the dead space is 150 ml, than 500 – 150 = 350 ml x 12 = 4200 millilitres
- alveolar ventilation is 4.2 l/min.
  Rapid, shallow respiration causes decrease of alveolar ventilation – see table

Dead space

- space of airways, in which does not occur the exchange of O_2 and CO_2 between the air and pulmonary capillary blood. It is important to distinguish between the anatomic dead space (ADS) and total (physiologic – TDS) dead space

In healthy individuals, the 2 dead space are identical.

- ADS – normal value is 150 ml is the volume of conductive zone of airways – from nose to terminal bronchioles
- TDS – is higher in disease states

the it is ADS + volume of air in alveoli, which are ventilated without blood perfusion.

The ADS can be measured by analysis of single – breath N_2 curves
The TDS can be calculated from the PCO_2 of alveolar gas and the tidal volume according to:

Bohr´s equation:

$$P_ECO_2 \times V_T = P_ACO_2 \times (V_T - V_D)$$

For example: P_ECO_2 = 28 mmHg
P_ACO_2 = 40 mmHg
V_T = 500 ml
then V_D = 150 ml

LUNG VOLUMES

- **Tidal volume (V_T) –** air that enters into lungs with each inspirium
- **Inspiratory reserve volume (IRV)** – the air inspired with a maximal insp. effort to normal inspiratory volume (in excess of the quiet V_T)
- **Expiratory reserve volume** (ERV) – the volume expired by an active exp. effort after quiet passive expiration
- **Residual volume** – air left in the lungs after a maximal expirium
  - collapse air + minimal air
- **Total lung capacity** – air in the lungs after maximal inspiration

The vital capacity - the largest volume of the air that can be expired after a maximal inpiratory effort VC = ERV + V_T + IRV

Timed-forced vital capacity – FVC – information about the strength of the resp. m.m. FVC in 1 second – the fraction of the FVC expired in 1 second (reduced in bronchoconstrictory disease – asthma)

Pulmonary surfactant

Structure of the alveolar system:

Total surface area – during exhalation – 80 m^2
- inhalation -120 m^2
= the largest body surface in direct contact with the external environment

300 million of alveoli in the human lungs of different sizes - instability of the system

Laplace´s law – $P = \frac{2x \text{ surface tension}}{r}$

P – pressure in the bubble
r - radius of the bubble

→ as air enters smaller bubbles – the pressure required to overcome surface tension increases. Smaller bubbles have a tendency to collapse to the bigger ones.

Stabilizing material in the lungs = a surface active agent – reducing the surface tension = pulmonary surfactant = substance lowering surface tension at the air-liquid interphase present in the alveoli and small airways with additional important physiological effects.

Composition of the surfactant

Amount: approx. 1 g (1 ml) in the whole adult lungs - monomolecular layer covering 80 m2 of the lung inner surface

S = a complex mixture of phospholipids. proteins, ions.

Phospholipids – 90% (tab. 1)
Proteins - SP-A, SP-B, SP-C 8%
Carbohydrates 2%
Ions - Ca^{2+}

Table

Phosphatidylcholine	73%
Phosphatidylglycerol	12%
Phosphatidylinositol	6%
Sphingomyelin	4%
Phosphatidyletanolamine	3%
Others	2%
	100%

Proteins: Specific proteins

– hydrophilic - **SP-A, SP-D**
(structural changes of SF, regulatory functions in metabolism of SF, role in the pulmonary defence system)

- hydrophobic – **SP-B, SP-C** (promotion of rapid PL insertion into air-liquid interface - biophysical activity)

Synthesis and secretion of SF

In the lungs: 40 different cell types
The alveoli are lined by epithelial cells – of

- the type I. – Pneumocyte I. (cover 95% of the a. surface)
- the type II. – Pneumocyte II. (5%):
  Cuboidal (9 microns) singly, small groups. They lie flat on the basal lamella, contain microvilli and more organelles than that of the pneumocytes I.

Pneumocyte II = the producers of the surfactant.

Biosynthesis of the surfactant

Pneumocytes II – ribosomes, mitochondria, lysosomes, Golgi´s complex, multi-vesicular bodies, large lamellar bodies (up to 25% of the cytoplasm = dispersions of phospholipids and proteins.

SF is produced in the endoplasmatic reticulum, transformed to the lamelar bodies. Maturation – transport near of the margin of pneumocyte II cell – secretion by exocytosis.

Alveolar metabolism of the surfactant

Destruction of the surfactant:
1) Reuptake by pneumocytes II – reutilisation of substrates
2) Phagocytosis and degradation by alveolar macrophages
3) Elimination through lymphatic and vascular system, and
4) Mucociliary transport

Structural forms of SF: - lamellar bodies
- tubular myelin
- monomolecular film

Control of synthesis and secretion of SF

Local **Neural** **Humoral**

Local:
Positive effect
-Ca^{2+},
-neutrophils,

- mechanical stretching of type II cells

Negative effect
– SP-A (negative biofeedback) – the more SP-A is present
in alveoli, the less of SF is synthetized and secreted

Neural control: symphatetic
parasymphatetic
both positive effect

Humoral control:
Positive effect
- corticosteroids
- T_3, T_4, TRH
- estrogens,
- prostaglandins (PGE2)

Negative effect
- hyperglycaemia (children of diabetic mothers – higher incidence of RDS)
- hyperinsulinemia
- androgens - inhibition of corticosteroids action
- general stimulatory effect for growth

Surfactant functions

1) **Mechanical stabilisation of alveoli and small airways decreasing surface tension at the air-liquid interphase.**

According to the Laplace law – by the same tension in the wall, the pressure inside the smaller alveoli is higher, and this is why when alveoli of different size are connected, alveoli with smaller diameter (and higher pressure inside) tend to empty to the larger alveoli. This would led to instability in system of alveoli!

Function of surfactant → to keep STABILITY in the lungs

The surface tension is kept low, when the alveoli become smaller during expiration. The surfactant increases the lung compliance (the change in lung volume per unit change in pleural pressure) and decreases work of breathing. **Increase in lung compliance and reduction of the work of breathing**

2) **Prevention of the pulmonary edema**
The decrease of the surface tension diminishes a negative forces for transudation of fluid into the interstitium or alveoli.

3) **Role in the immune defence system of the lung**
- Positive chemotactic effect for macrophages
- The surfactant increases phagocytosis
- Prevention against an adhesion of microorganisms – via a decrease of the surface tension of the pathogenic microbes

4) **Transports solid inhaled particles or damaged cells from alveolar compartment**
Transport of particles into the wall of alveoli – pulmonary macrophages

5) **Facilitation of the free airflow and low resistance in the airways**
Facilitation of the mucociliar transport and airflow through terminal bronchioles

Surfactant disorders in some pulmonary diseases

1) Idiopatic respiratory distress syndrome (IRDS)

Surfactant in perinatal period
Pneumocytes II – start of the surfactant production in 30th – 32nd week of gestational age

Immature surfactant – predominance of the phosphatidylinositol
(mature – phosphatidylglycerol)

Fetus secretes the surfactant through airways to the amniotic fluid –
- determination of the maturity from the fluid.

The first breath – the increase of the surfactant secretion.

Surfactant deficiency = idiopathic respiratory syndrom (IRDS) –
- in newborns. In adults ARDS.

Prematurely born children – insufficient function of SF
→ development of respiratory distress syndrome (IRDS - idiopatic)

Symptoms: tachypnoe, dyspnoe, expiratory grunting, decrease in compliance, increase of work of breathing, hypoxemia,
acidosis, ...)

2) Adult respiratory distress syndrome (ARDS)
3) Pneumonia
4) Meconium aspiration syndrome
5) Congenital diaphragmatic hernia
6) Pulmonary edema, ...

Surfactant replacement therapy

Aims: 1) to deliver surfactant to the lungs
2) to stimulate metabolism of endogenous surfactant

Types of exogenous surfactants:
Natural: from amniotic fluid, bovinne, porcinne
(Curosurf, Alveofact)
Artificial: synthetic (Exosurf)

Way of administration: intratracheally (bolus dose, nebulisation)

Timing of therapy: 1) prophylactic
2) rescue

Effects of surfactant replacement:

- immediate – increase in oxygenation, increase in the lung compliance

- later – reduction of FiO_2 and ventilatory pressure, to shorten oxygenotherapy and artificial ventilation

THE TRANSPORT OF OXYGEN AND CARBON DIOXIDE

Ventilation = the exchange of air between the environments and the lungs

Diffusion – of oxygen from the alveoli into the blood
- of CO_2 - in the opposite direction

The exchange of the gases – theories
1) active – secretory (Bohr, Haldane)
2) passive – diffusion on the basis of pressure differences – concentration gradients (Barcroft, Krogh)

1) The transport of oxygen

O_2 - dissolved in plasma
- bound to hemoglobin

a) Physically dissolved O_2:

1 l plasma – 3 ml O_2 (3 ml %)

Linear relatioship – the amount of O_2 dissolved in plasma is proportional to the PO_2 (Henry´s law): „The amount of dissolved gas in fluis depends on the volume of the fluid, on the pressure of the gas and on the solubility coefficient (at constant temperature).

$C_SO_2 = 0.024$
$C_SO_2 = 0.51$ (20-25 x more)

C_S = amount of a gas (in 1) dissolved in 1 l of a fluid at P = 760 mmHg

b) O_2 combined with hemoglobin

1 g Hb ← 1.34 ml O_2 = Hűfner´s coefficient
1 l of blood – 160 g of Hb = 160 x 1.34 = 214 ml O_2 =
= **O_2 capacity** = 100% (90-100 %)

Oxygen hemoglobin dissociation curve:

= the basic relationship between percentage of O_2 saturation of Hb and PO_2.

Factors affecting the affinity of Hb for O_2

1) **CO_2 + H^+** - shift the dissociation curve to the right – Bohr Effect
2) B**ody temperature**
   - Increase of BT – evokes a decrease of the affinity between Hb and O_2 – shift of the curve to the right.
   - The decrease of BT – an opposite effect – hibernation.

3) **2,3-DPG** – metabolit in red cells metabolism (Embden – Mayerhof pathway) – a product of glycolysis.
   2,3-DPG shifts the curve to the right – release O_2, reduction the affinity of Hb for O_2.

Carbon dioxide transport

$PaCO_2$ = 40 mmHg (5.3 kPa); PvO_2 = 46 mmHg (6.1 kPa)

1) CO_2 dissolved in plasma
2) CO_2 dissolved in erythrocytes
3) Biocarbonate ions
4) CO_2 bound with proteins

1,2) CO_2 dissolved in plasma and in erythrocytes: 5% CO_2

$$CO_2 + H_2O \underset{\leftarrow}{\overset{CA}{\rightarrow}} H_2CO_3 \underset{\leftarrow}{\overset{CA}{\rightarrow}} H^+ + HCO_3^-$$

3) Bicarbonate ions: 75-80 % CO_2

$NaHCO_3$ – plasma
$KHCO_3$ - erythrocytes

$$\frac{H_2CO_3}{NaHCO_3 + KHCO_3} = \frac{1}{20}$$

4) CO_2 bound with proteins: 15-20 %
   a) with free amino groups of various plasma proteins to form carbamino compounds
   b) with the free amino ($-NH_2$) sites of the hemoglobin

$$HbNH_2 + CO_2 \underset{\leftarrow}{\rightarrow} HbNHCOOH$$

Carbon dioxide dissociation curve

The relationship between CO_2 pressure and CO_2 content is nearly linear.
Factors affecting CO_2 transport:
O_2 – increasing the PO_2 – shift to the right = Haldane effect = analogy to Bohr effect.

Partial pressures of O_2, CO_2

Air – mixture of gases (O_2, CO_2, N_2 ...)
Pressure caused by one gas alone = partial pressure

		%	P	
Atmospheric air:	O_2	= 20.93	150 mmHg	20 kPa
	CO_2	= 0.04	0.3	0.04
	N_2	= 78.1	560	75
Alveolar air:	O_2	= 14	100	13.3
	CO_2	= 5.6	40	5.3
Arterial blood:	PaO_2		95	12.6
	$PaCO_2$		40	5.3
Venous blood: (mixed)	PvO_2		40	5.3
	$PvCO_2$		46	6.1

Oxygen Therapy

= a lifesaving modality in clinical medicine
Indications: hypoxemia, hypoxia (mainly hypoxic hypoxia)
Applications: incubators, intranasal catheter, O_2 mask
When 100% O_2 (FiO_2 = 1.0) is inhaled – the Hb is fully saturated and 5x is increased O_2 dissolved in plasma (from 3 to 14-15 ml/l).
PaO_2 = 700 mmHg
(93 kPa) – in healthy humans.

Adverse effects of the oxygen therapy

1) Irritation of airways mucosa with inhalation of dry (non humidified) and cold O_2
2) Changes in the lung
   - a decrease of the surfactant production (exposure for 24-28 hours and more)
   - an inhibition of pulmonary macrophages activity
   - an inhibition of the mucociliary transport
   - lung edema
3) Vasoconstriction
   - cerebral
   - retinal – ischemia – formation of the fibrotic scares – visual deffects –
   - blindness – retrolental firbroplasia
4) Effect on the brain and other organs – experimental knowledges – a decrease of the brain GABA content, ATP.

Hyperbaric oxygenation

Application of the oxygen in hyperbaric conditions (2-3 atm. = 2-3 x 760 mmHg) –
- application of the pressure on the whole body.

Increase of O_2 in physical solution in plasma.
PaO_2 = 2000 mmHg – sufficient to supply tissues.

Method – in hyperbaric chambers, tanks
Indications – inactivation of Hb functions – intoxication with CO, methemoglobinemie, cyanide poisoning, treatment of Bűrger´s disease, disturbances of vascularisation (ulcus cruris), surgery for certain forms of congenital heart disease, gas gangren.

Limitation of the hyperbaric oxygen exposure to less than 5 hours by 3 atm.

ARTIFICIAL VENTILATION

= artificial method ensures a flow of gas into (from) the alveoli

Ventilator – a device that replaces or augments the function of the inspiratory muscles – to ensure a flow of gas into the alveoli.

Classification of artificial ventilation:

INNP = intermittent negative pressure ventilation – by reducing the ambient pressure around the thorax.
Neg. P ventilators - acting on – the thorax - the whole body below the neck (tank respirator – **„iron lungs“**)

Principle: The pressure in the chamber is reduced cyclically by means of a large volume displacement pump, that cousing the lungs to expand and contract.
In the past – for poliomyelitis victims – now for overnight support for patients with respiratory muscle weakness.
Disadvantages – it occupies much space, access to the patient – poor neck seal

IPPV = intermittent positive pressure ventilation

Principle: IPPV ventilators produce inspiration – inflation – expiration is usually passive.

Types: Time/pressure/volume/ combined cycled machines.
Time cycled ventilators switch between inspiration and expiration after a preset time interval.
Pressure cycled – switch when a preset airway pressure threshold has been reached.
Volume cycled – cycle when a preset tidal volume has been delivered.

IPPV + retarded – delayed expirium

IPPV + PEEP !!!

Benefit – the functional residual capacity can be maintained by leaving a constant standing pressure in the lungs, keeping them slightly inflated even at the end of expiration.
PEEP – causes – an increase in PaO_2

Disadvantage: increase in intrathoracic pressure – diminuation in venous return to the heart, decrease in cardiac output

Special Techniques:
MANDATORY VENTILATION

- allows the patient to breathe spontaneously through the ventilatory circuit.

Non-synchronised:
At predetermined intervals a positive pressure **artificial breath** is provided by the ventilator indepedently of the patients spontaneous breathing = without synchronisation.

Synchronised:
For avoiding of the mandatory breath during the period of the spontaneous breath. Electronic control. Any spontaneous inspiratory activity by the patient is sensed by „trigger" – pressure sensor and then expiratory valve is closed – inspiratory valve is opened. The flow of gas through the inspiratory valve is matched to the patient inspiratory flow. This allowed the patient to breath spontaneously through the ventilator. Synchronisation between patient and ventilator.

High frequency ventilation
High frequency IPPV (60 – 120/min)
HF jet ventilation HFJV (150 – 600/min)
HFJV – brief, frequently repeated pulses of gas are directed from a high pressure generator down the airways. VT and Paw are low.
HF oscillation ventilation HFOV (up to 5000/min)
HFOV – oscillate gas in the airways using a piston pump or diaphragm pump. VT are very small, gas movement occurs by mechanisms other than VT.

Non-invasive ventilation

CNP – continuous negative pressure – analogy to the „iron lungs".
Keeping the negative pressure around the chest (body) to hold alveoli opened.
Premature newborns with RDS – *Pulmarca*. Spontaneous breathing on the shifted FRC level.

CPAP – continuous positive airway pressure – spontaneously breathing patient in whom Paw is held positive (5 – 10 cm H_2O in relation to atmospheric pressure throughout the respiratory cycle.
Nasal CPAP – in premature newborns with RDS, in adults – Sleep Apnea Syndrome, snoring).
Benefit – keeping the alveoli to be opened in all phases of the respiratory cycle – anti atelectatic effect.

Effects of different barometric pressures on organism

A) Effects of high atmospheric pressure-hyperbaric conditions
Diving
Sea (water) depth – to each 10 m – barometric pressure increases by 1 atm. (760 mmHg) – subject in the depth is exposed to a P 2 atm (1 – by the air + + 1 by the water).
Effect of depth on the lung volume – Boyle, s Law: „The volume of gas is compressed in the higher P and the volume is inversely proportional to the pressure".

Compression of gases – in the depth 10 m – half of the lung volume. Increased P can collapse alveoli.

Necessity to breath from the special devices (aqualungs) – to maintain the same pressure in the lungs than in environment. By the P outside is regulated P in the gas tanks and P in aw and alveolar compartment.

Effect of depth on the partial pressure of gas: Nitrogen, oxygen, carbon dioxide:

High nitrogen P:
At high pressure it is diluted in the plasma – at 4-5 atm. P Nitrogen euforia – like alcohol intoxication, at 35 and more atm. narcosis.N dissolves freely in the fats of the body and also in the membranes of the neurons.

High oxygen P:
Oxygen toxicity – affects CNS – epileptic like convulsions – up coma at 3 atm. P after about 1 hour. Cause – production of oxidizing free radicals – oxidative destruction of cells elements.

Carbon dioxide toxicity at high P:
- no problem – the rate of the CO_2 production in the divers body is the same.

Effect of decompression

Decompression Sickness
(Caisson Disease, divers paralysis)

In the depth the large amount of nitrogen have dissolved in his body and then sudden return to normal atm. P can develop production of N bubbles intracellularly (extracellularly – Boyle´s Law. The plug the small blood vessels.

Symptoms: 1) Pain in the joints and muscles of the legs and arms
2) CNS symptoms: dizziness, paralysis, collapse, coma, unconsciousness
3) Shortness of breath, pulmonary edema, death

Treatment:
By special decompression tables – return to previous depth in hyperbaric chamber – and return slowly to normal P.

REGULATION OF BREATHING

1/ NEURAL
2/ HUMORAL

Neural for: -regulation of ventilation
- protection and defence of the RS

Humoral for: modification of ventilation according to
- **oxygen needs**
- **elimination of carbon dioxide**

NEURAL REGULATION OF BREATHING

a/ Medullary respiratory centers

Primary respiratory centers:

- **Inspiratory part:** dorsal respiratory group (ventro-lateral nucleus of tractus solitarius)
- **Expiratory part**: area of ncl. retrofacialis, Bötzinger´s complex
- **Mixed area:** - inspiratory + expiratory neurons – ventral respiratory group - innervation of larynx – ncl. ambiguus, ncl. para – and retroambigualis

b/ Pontine respiratory centers

1) **The apneustic center** (ncl. reticularis, area vestibularis)
2) **The pneumotaxic center** (ncl. parabrachialis, ncl. Kölliker – Fusse)

Modifications of respiratory centers activities

a) Modification by higher CNS centers

1) **Cerebral cortex** – voluntary control (hyperventilation, apnoea,vocalization, speech...)
2) **Limbic structures and hypothalamus** (changes in emotions –crying, laughing, panting ...)

Voluntary and automatic control of respiratory muscle function are separately.

Voluntary control of breathing:
Corticospinal pathway – in dorsolateral spinal medulla (damaged = ***syndrome of the automatic breathing***)

Automatic control of breathing:
Bulbospinal pathway – in ventrolateral tract (damaged = Ondine´s curse).

b) Modification of breathing by peripheral receptors

1) Receptors of the nose

Olphactoric and trigeminal endings → mechanical, chemical and thermal stimuli
Involved in:
Regulation of the quiet breathing (nasothoracic reflex)
Protective and defensive airway reflexes

2) Receptors of the naso – and oropharynx

The endings of the n. Vth, VIIth, Ixth, Xth
Stimuly:Mechanical, thermal

Involved in:Regulation of the quiet breathing (stimulation of the inspirium?)

3) Receptors of the larynx

a/ **Mechanoreceptors** – pressure sensitive, drive receptors (proprioceptors)

b) **Cold receptors** – inspiratory airflow
c) **Laryngeal irritant receptors** (chemical and mechanical stimuli)
d) **Chemosensitive – fluid receptors**
e) Others – **nonspecific**

Lower airways and lung receptors

1) Pulmonary stretch receptors – mechanoreceptors of the airway in smooth muscles
Slowly adapting receptors
- Low – threshold (tonic) receptors
- High – threshold (phasic) receptors

Stimuli: Increase in volume and pressure in airways and lungs
Effects:
Hering – Breuer inflation reflex
a) inhibiting inspirium
b) promoting expirium

2) Irritant receptors – C-fiber receptors of the airways - cough receptors
Rapidly adapting receptors

Stimuli: Inhaled irritants, mechanical deformation of the airway mucosa
Effects:
Coughing, hyperpnoea, bronchoconstriction, laryngoconstriction, hypersecretion of mucus.

3) C-fiber receptors of the lungs
J-receptors (juxtapulmonary capillary)

Stimuli:
Mechanical: an increase in interstitial lung pressure (edema, embolism, „wet lungs“ ...)
Chemical: smoke (cigarette), capsaicin, PDG, histamine, serotonin, prostaglandins

Effects:
Pulmonary chemoreflex – 2 phases: depressive and excitatory
Bronchoconstriction, laryngoconstriction

J - reflex (Paintal) – the inhibition of mono- and polysynaptic reflexes – in extreme physical effort

4) Non – specific receptors affecting respiration
- Proprioreceptors, muscle spindles (thorax, abdomen)
- Cutaneous receptors (thermo-, tactile ...)
- High pressure receptors in circulation
- Mechanoreceptors of the eye
- Senses – visual, acustic, vestibular ...

CHEMICAL – HUMORAL REGULATION OF BREATHING

Regulation of ventilation by PO_2, PCO_2, pH

Sensors-monitors: chemoreceptors: - peripheral
- central

Peripheral chemoreceptors:

- glomus caroticum
- glomus aorticum (n. Xth)

Tonic activity

Effects on ventilation:
A decrease in PaO_2 and / or an increase in $PaCO_2$ – the frequency of nerve impulses increases:
Effect: hyperventilation

Interaction of chemical factors affecting ventilation – positive hypoxic - hypercapnic relationship

Effects on cardiovascular system: redistribution of the blood into the vital most important organs, hypertensive reaction, bradycardia.

Central chemoreceptors:

Location: ventrolateral surfaces of the medulla (H^+, Mitchell, Loeschke and Schlaefke zone)

Stimulus: An increase in PCO_2 and H^+ (a decrease in pH) in the cerebrospinal and cerebral interstitial fluid

Effects: hyperventilation in respiratory and metabolic acidosis

PROTECTIVE AND DEFENSIVE REFLEXES OF THE AIRWAYS

Protective (preventive) reflexes:

- **Kratschmer´s apnoeic reflex:** nasal origin (n.Vth)
  Stimuli: chemical irritation of nasal mucosa
  Effects:
  - inhibition of ventilation
  - laryngoconstriction
  - peripheral vasoconstriction – redistribution of the blood
  - bradycardia

- **Diving reflex** (n.Vth) nasal and perioral region
  Stimuli: cold (water, air)
  Effects: the same as in Kratschmer´ s reflex
  Oxygen conserving reflexes

Defensive reflexes:

Sneezing – mechanical stimulation of nasal mucosa (n.V.)

1) deep inspirations (intensification through HB reflex)
2) expiratory effort – compressive phase
- expulsive phase

Coughing – laryngo-pharyngeal / tracheobronchial

1) preparatory inspiration
2) expiratory effort – compressive phase ($P_{i.p.}$ = 100-200 mmHg)
- function of glottis
- expulsive phase – airflow velocity – 120 m/s (hurricane 50 m/s)

Expiration reflex – medial margin of vocal folds – only expiratory effort

Aspiration reflex - naso – oropharynx – only inspiratory effort.
Sniff-like reflex.