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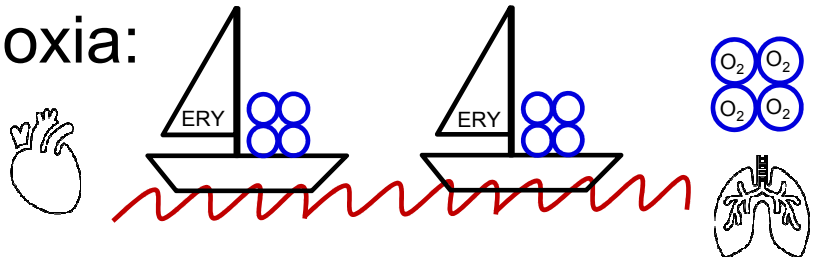
Respiratory system. Compendium.

Questions for the oral exam

- A22: Hypoxia and ischemia
- A25: Lung ventilation, volumes, measurement
- A26: Dead space, measurement
- A27: Resistance of airways, measurement
- A28: Maximal respiratory flow - volume curve (spirogram)
- A45: Alveolar surface tension. Surfactant
- A46: Compliance of lungs. Respiratory work. Pneumothorax
- A47: Composition of atmospheric and alveolar air. Gas exchange in lungs and tissues
- A48: Transport of O_2. Oxygen - haemoglobin dissociation curve. Transport of CO_2
- A49: Regulation of ventilation
- A50: Respiratory responses to irritants

A22: Hypoxia and ischemia

- Hypoxia is a general name for a lack of oxygen in the body or individual tissues
- Ischemia, meaning insufficient blood flow to a tissue, can also result in hypoxia
- The most common types of hypoxia:
  - Hypoxic
  - Transport (anemic)
  - Ischemic (stagnation)
  - Histotoxic



ERY: ♀ 3.4 – 4.4 * 10^{12}/l
♂ 4.5 – 5.5 * 10^{12}/l
pO_2: 21kPa

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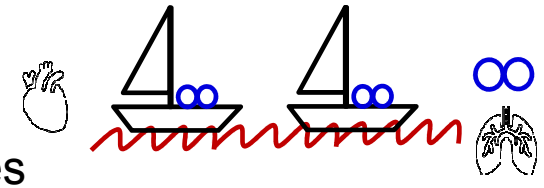
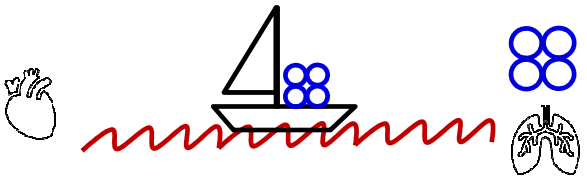
A22: Hypoxia and ischemia

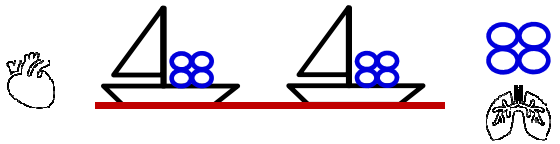
- Hypoxic:
  - physiological: stay at higher altitudes
  - ↓ pO_2; N Ery
  - pathological: hypoventilation during lung or neuromuscular diseases
  - ↓ ventilation; N pO_2; N Ery



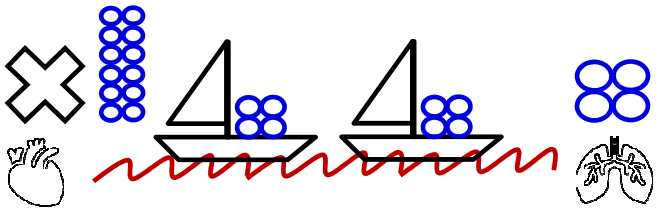
- Transport (anemic):
  - reduced transport capacity of blood for oxygen (anemia, blood loss)
  - N pO_2; ↓ Ery/Hb



- Ischemic (stagnation):
  - restricted blood flow to tissue (heart failure, obstruction of an artery)
  - N pO_2; N Ery



- Histotoxic
  - cells are unable to utilize oxygen (cyanide poisoning)
  - N pO_2; N Ery



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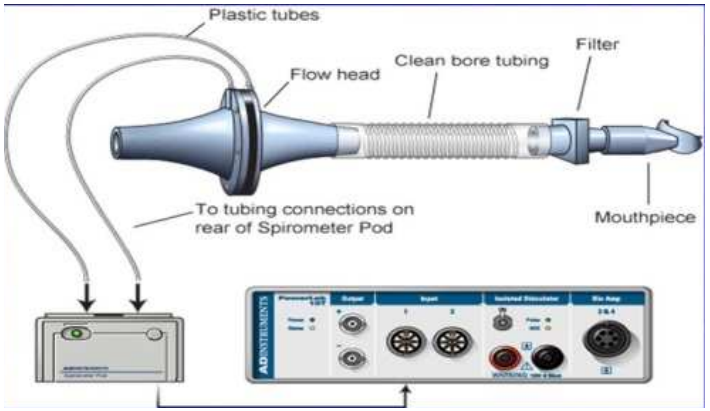
A25: Lung ventilation, volumes, measurement

- *Ventilation*, or breathing, is the movement of air through the conducting passages between the atmosphere and the lungs
- *Principle*: determination the air flow velocity from the measured pressure differences between the inner and outer spirometer membranes, the volumes being calculated (PowerLab spirometry)



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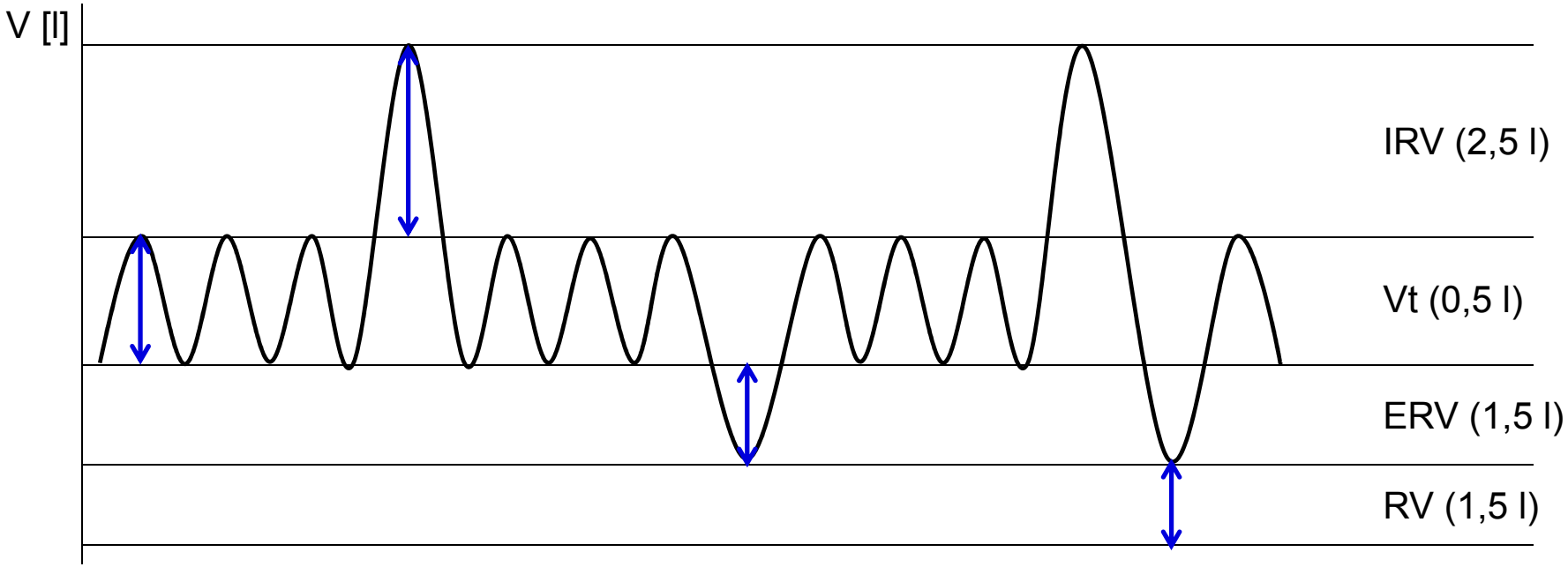
A25: Lung ventilation, volumes, measurement



- ***Tidal volume* (TV)** – the volume of air that enters the lungs during each inspiration (or the volume that is exhaled during every expiration).
- ***Inspiratory reserve volume (IRV)*** – the maximal amount of additional air that can be drawn into the lungs by determined effort after a normal inspiration at rest.
- ***Expiratory reserve volume (ERV)*** – the additional amount of air that can be exhaled from the lungs by determined effort after a normal expiration.
- ***Residual volume (RV)*** – the volume of air still remaining in the lungs after the most forcible expiration possible.

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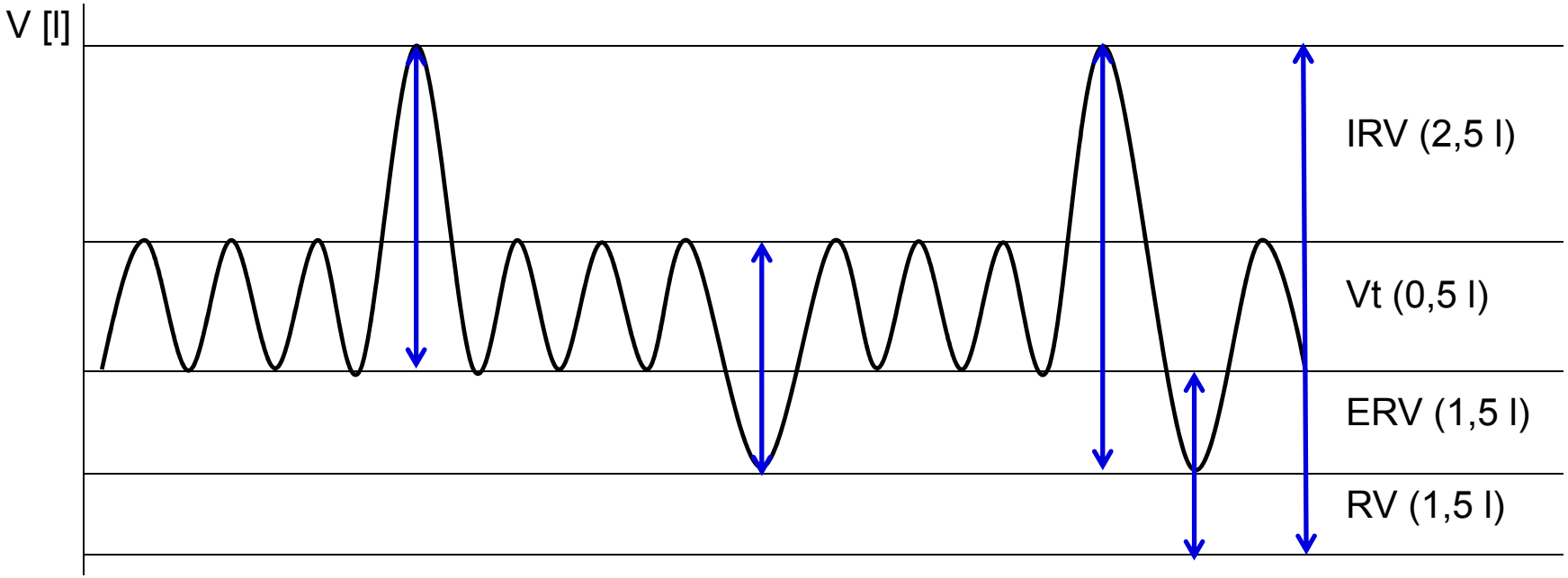
A25: Lung ventilation, volumes, measurement



Lung capacity:

- *VC = VT + IRV + ERV*
- *TLC = VC + RV*
- *FRC = ERV + RV*
- *IC = IRV + VT*
- *EC = ERV + VT*

Dynamic lung volumes:

- VE
- MMV

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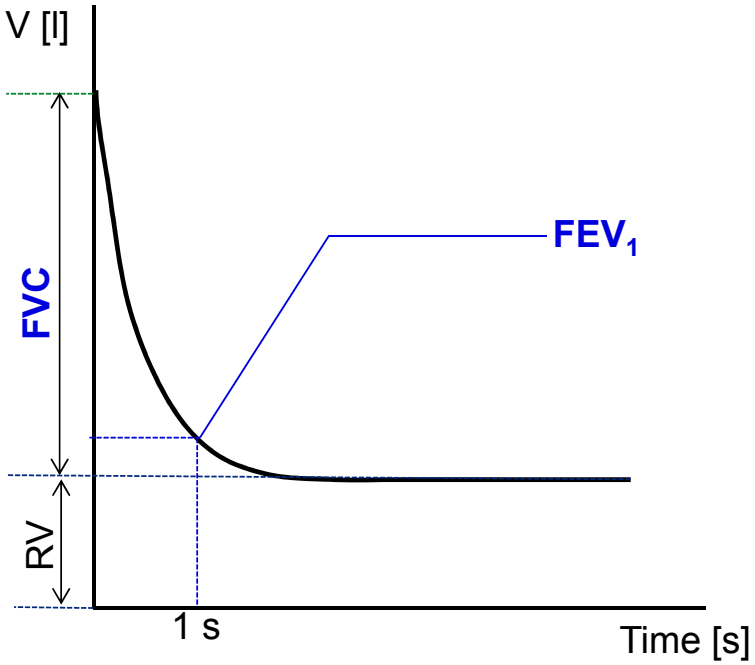
A25: Lung ventilation, volumes, measurement

Dynamic lung volumes



- **FVC** – the maximum volume of air that can be exhaled after maximum inhale
- **FEV_1** – the volume of air exhaled with the greatest effort in 1 second after maximum inhale
- **FEV_1/FVC (%)** – Tiffeneau index – around 0,8 (80 %)

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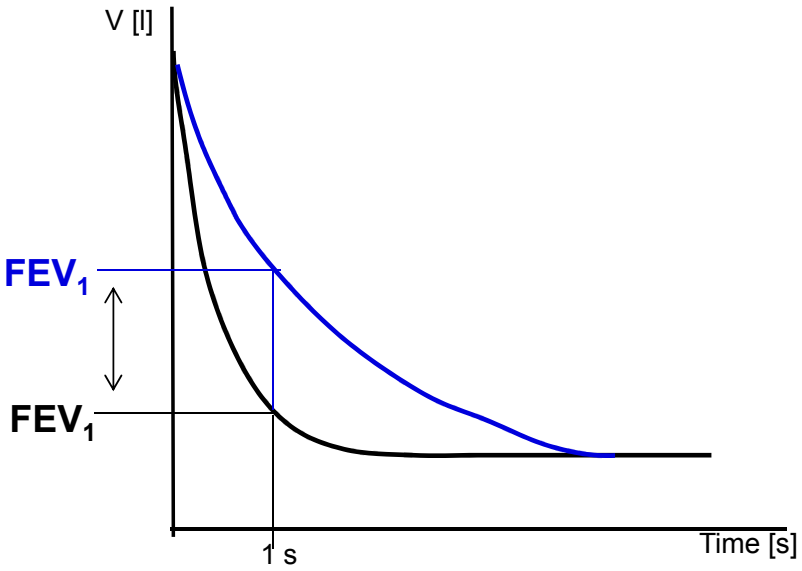
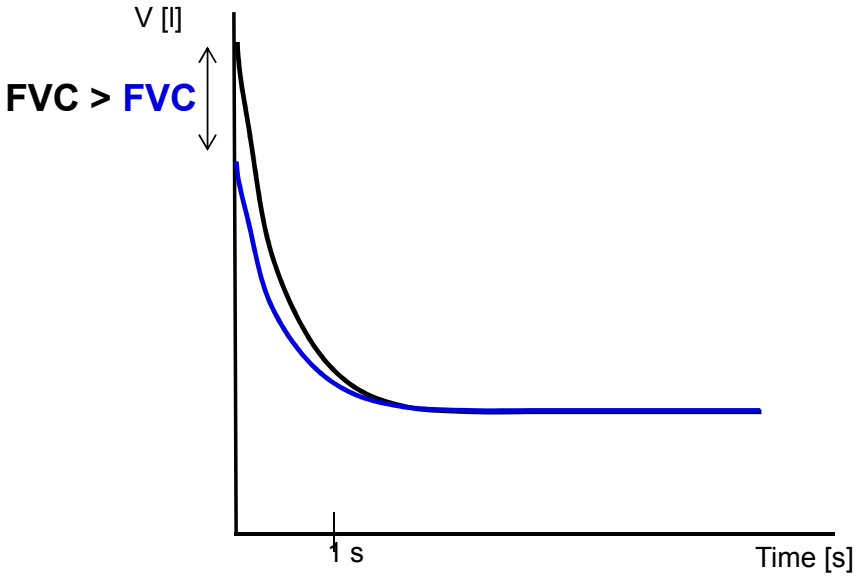
A25: Lung ventilation, volumes, measurement



Obstruction lung disease
(FVC=N; FEV_1=↓)
- tracheal stenosis
- astma bronchiale
- CHOPN
- tumor



Restrictive lung disease
(FVC=↓; FEV_1=N)

Pulmonary etiology
- pulmonary fibrosis
- lung resection
- pulmonary edema
- pneumonia

Extrapulmonary etiology
- ascites
- kyphoscoliosis
- burns
- high diaphragm condition

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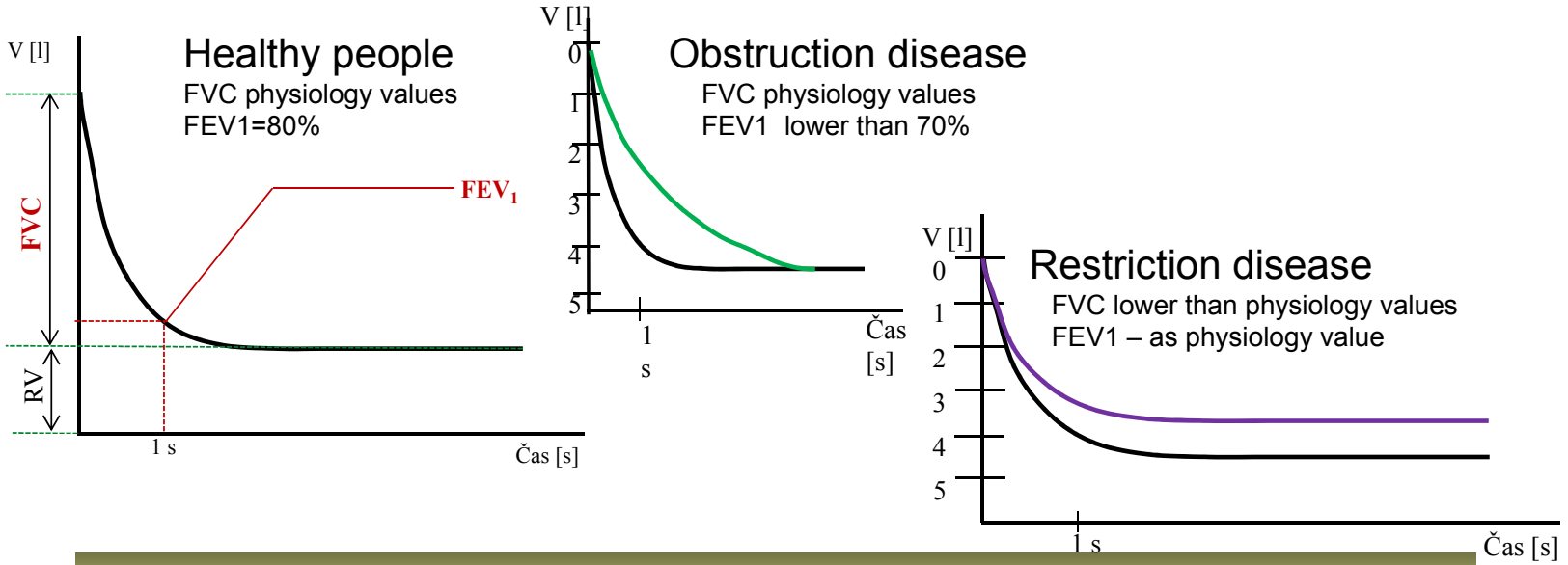
FUNCTIONAL INVESTIGATION OF THE LUNGS

- **TIMED VITAL CAPACITY** (***FEV*$_1$** - forced expiratory volume per 1 s)

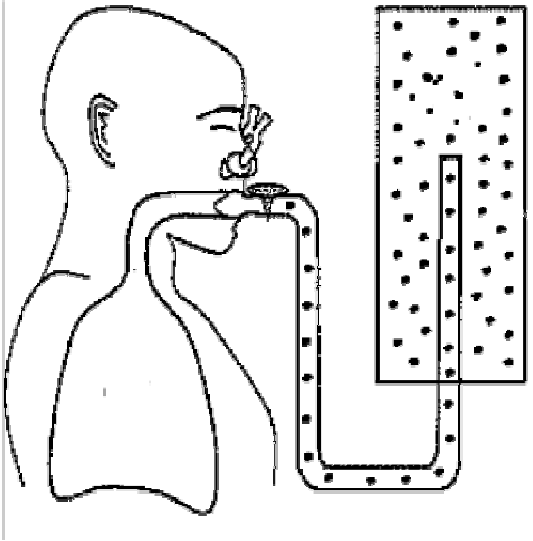


- **PULMONARY MINUTE VENTILATION *RMV* (respiratory minute volume) at rest** (0.5 l x 12 breathes/min = 6 l/min)
- **MAXIMAL VOLUNTARY VENTILATION (*MVV*)** (125-170 l/min)
- **PEAK EXPIRATORY FLOW RATE (*PEFR*)** (~10 l/s)

A25: Lung ventilation, volumes, measurement

Helium dilution method – residual volume

V_1
c_1

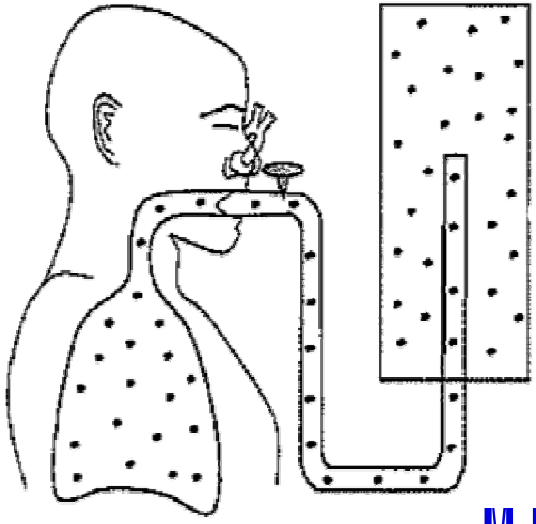


$c=\frac{n}{V}$

$$V_1 \times c_1 = (RV + V_1) \times c_2$$

$$RV = \frac{V_1 \times c_1}{c_2} - V_1$$

$V_2=RV+V_1$
c_2



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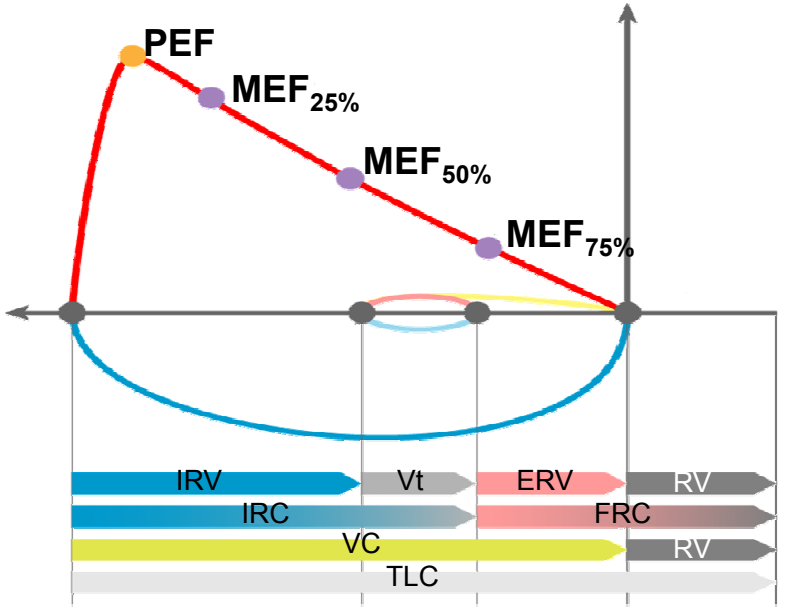
A28: Maximal respiratory flow - volume curve (spirogram)

Principle: the measurement of the air flow velocity according to the speed of the turbine and the volumes are calculated (Cosmed).

- **PEF** – peek expiratory flow; the highest speed of air flow at peak of exhale
- **MEF** – maximum expiratory flow rates at different FVC levels, which is still to be exhaled (75 %, 50 % and 25 % of FVC)



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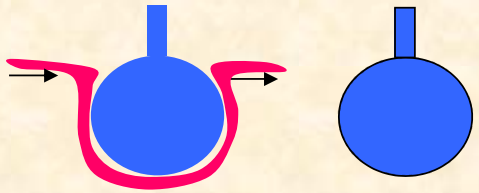
DEAD SPACE

TOTAL GAS VOLUME NOT EQUILIBRATED WITH BLOOD
(without exchange of gasses)

- **ANATOMICAL dead space - volume of air passages**
- **FUNCTIONAL (total) dead space**

ANATOMICAL dead space + total VOLUME of ALVEOLI without functional capillary bed



IN HEALTHY INDIVIDUALS
both spaces are practically identical

V_T tidal volume ~ **500 ml**

$V_T = V_A + V_D$

V_A part of tidal volume entering alveoli ~ **350 ml**

V_D part of tidal volume remaining in the dead space ~ **150 ml**

f = 12/min

$\dot{V} = V_T \times f$

PULMONARY MINUTE VENTILATION

6 l/min

$\dot{V}_A = V_A \times f$

ALVEOLAR VENTILATION

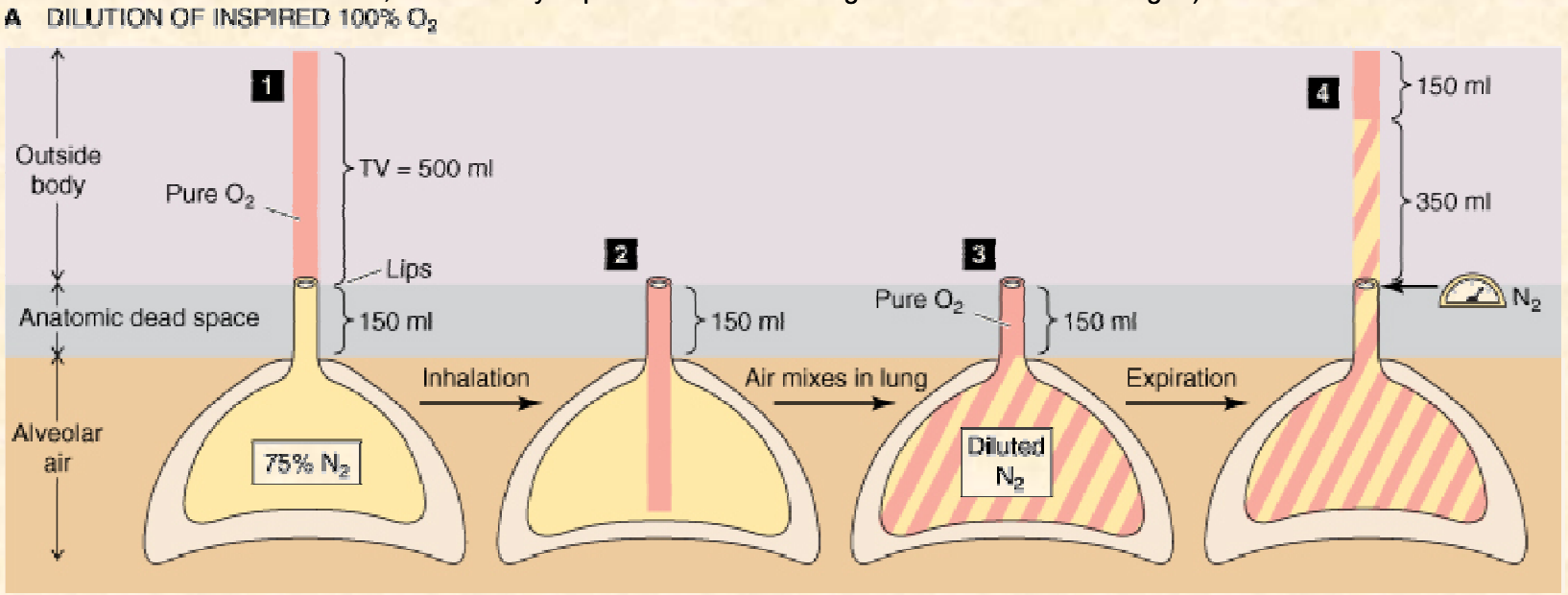
4.2 l/min

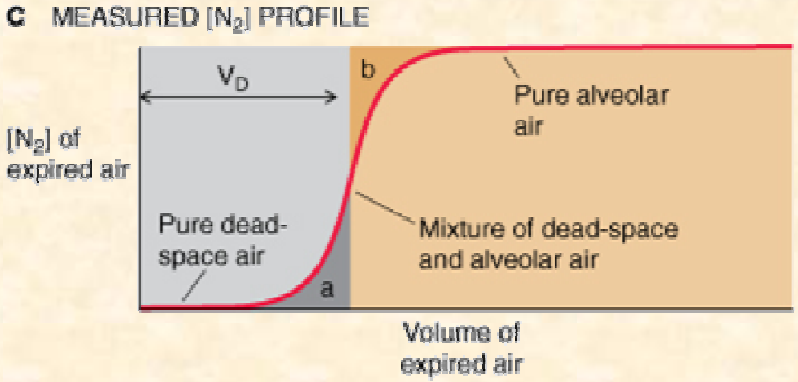
$\dot{V}_D = V_D \times f$

DEAD SPACE VENTILATION

1.8 l/min

DEAD SPACE – nitrogen test (force inspiration of pure O2, follow slowly expiration with monitoring of concentration of nitrogen)

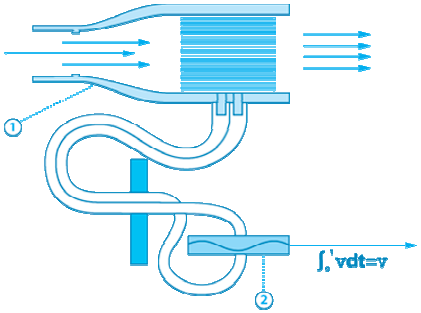




A27: Resistance of airways, measurement

Pneumotachograph:

- tubes of the same diameter, parallel arranged
- measures the differences in air pressure at the beginning and end of the pneumotachograph in proportion to the velocity of the inhaled or exhaled air



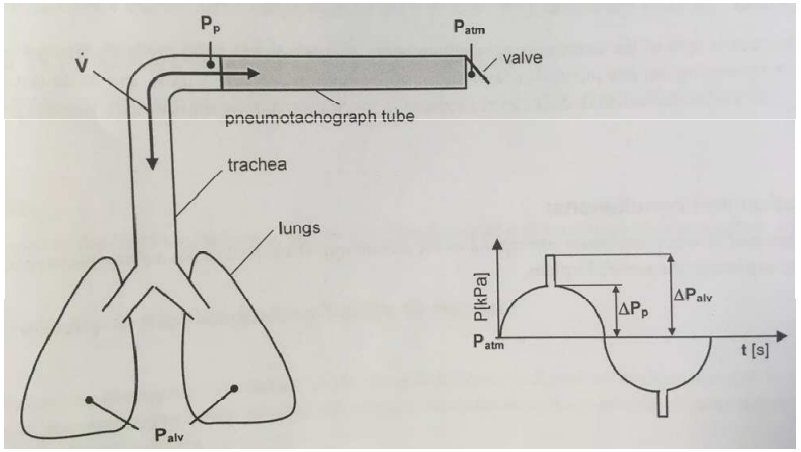
$$\dot{V} = \frac{\Delta P}{R}$$

$$\Delta P_p = P_p - P_{atm}$$

$$\Delta P_{alv} = P_{alv} - P_{atm}$$

$$R_d = R_p \cdot \left(\frac{\Delta P_{alv}}{\Delta P_p} - 1 \right)$$

$$\frac{P_p - P_{atm}}{R_p} = \dot{V} = \frac{P_{alv} - P_p}{R_d}$$



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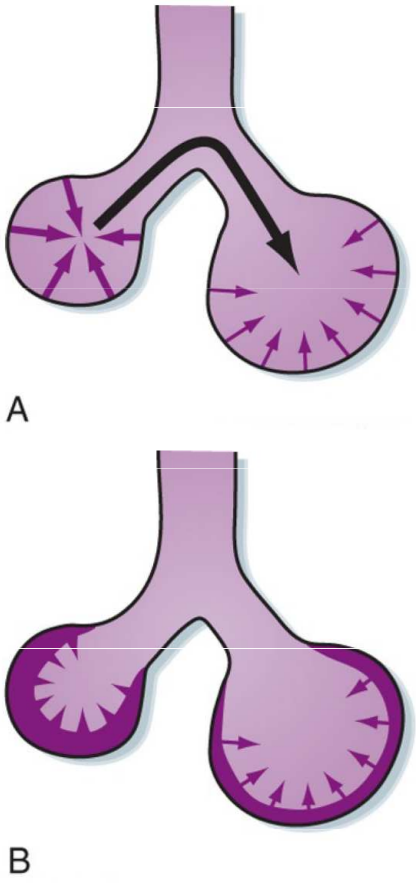
A45: Alveolar surface tension. Surfactant



- pneumocytes typ II
- reduces the surface tension depending on the size of the alveolus
- increases lung compliance, reduces breathing work

The Laplace law (in constant tension):
the alveolus with bigger radius has lower pressure
→ the air would move from a smaller alveolus to a bigger one
→ collapse of smaller alveoli

$$P = \frac{2T}{r}$$

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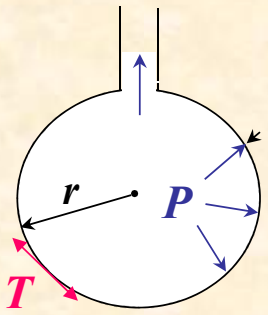
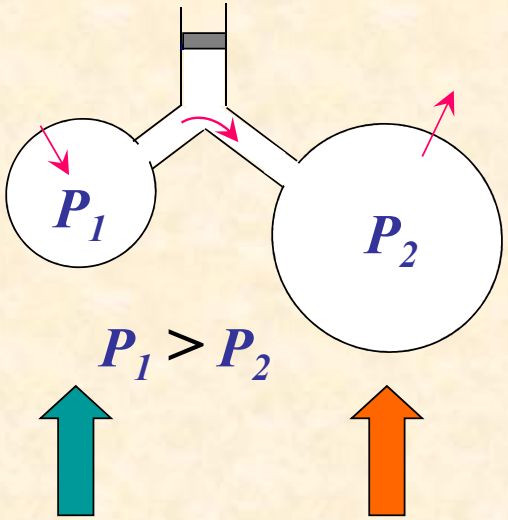
LAW OF LAPLACE

spherical structures



$$P = \frac{2T}{r}$$

?



P pressure

r radius

T surface tension

PATHOLOGY

- **COLLAPSE OF ALVEOLI - ATELECTASIS**
- **EXPANSION OF ALVEOLI**

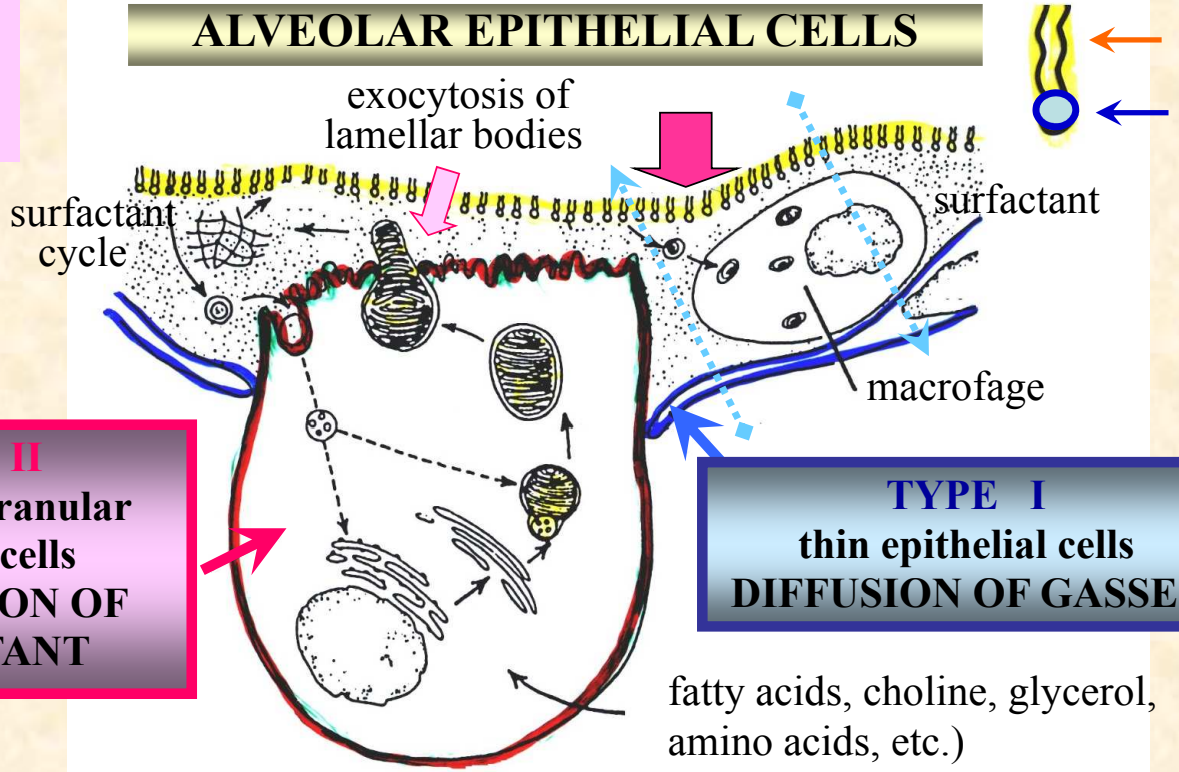
SURFACTANT

SURFACE TENSION LOWERING AGENT

EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID
dipalmitoyl
fosfatidyl cholin

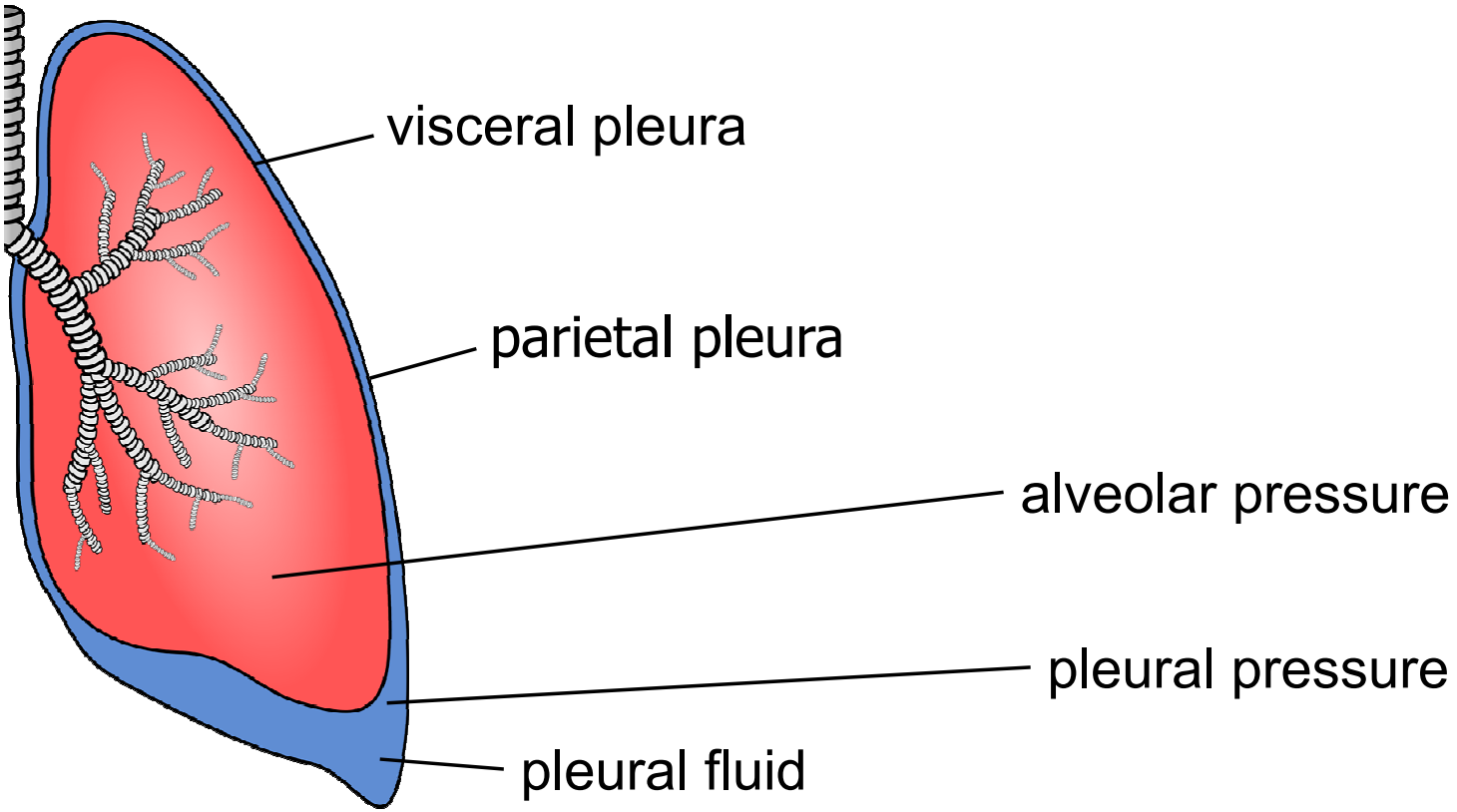
ALVEOLAR EPITHELIAL CELLS

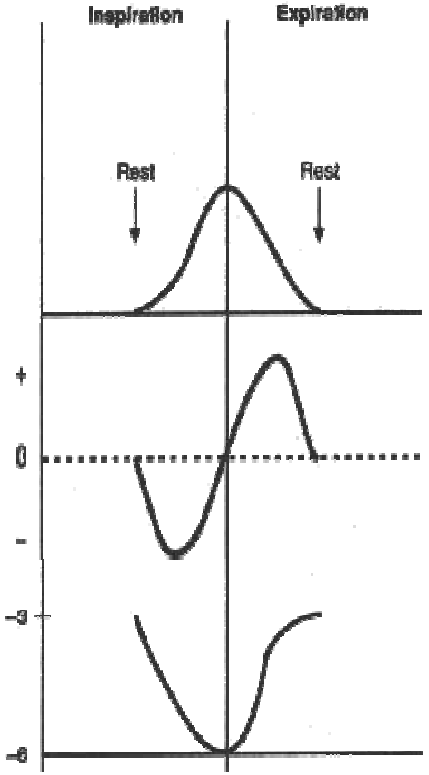


TYPE II
specialized granular epithelial cells
PRODUCTION OF SURFACTANT

TYPE I
thin epithelial cells
DIFFUSION OF GASSES

A46: Compliance of lungs. Respiratory work. Pneumothorax





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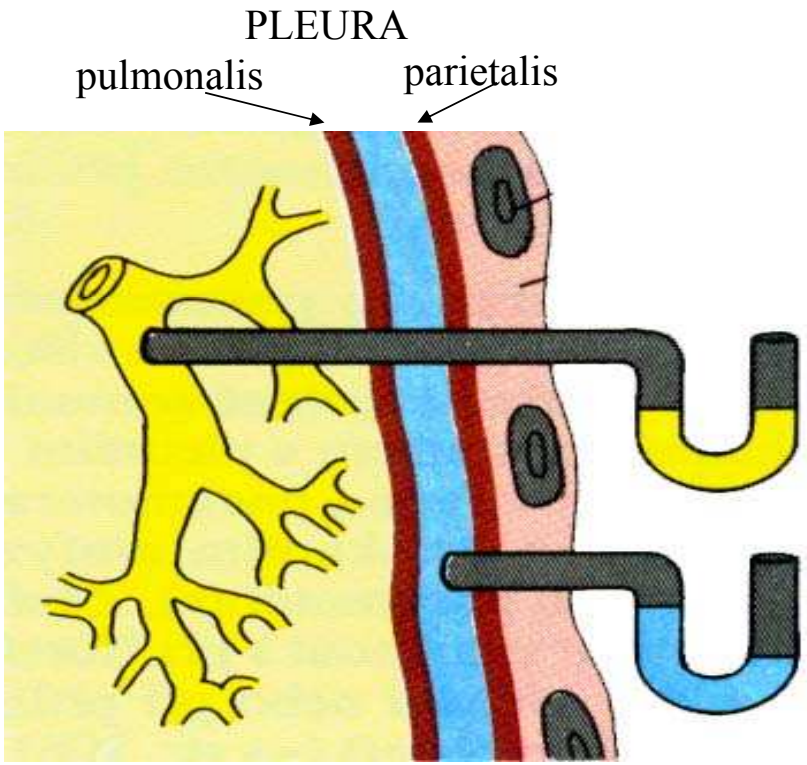
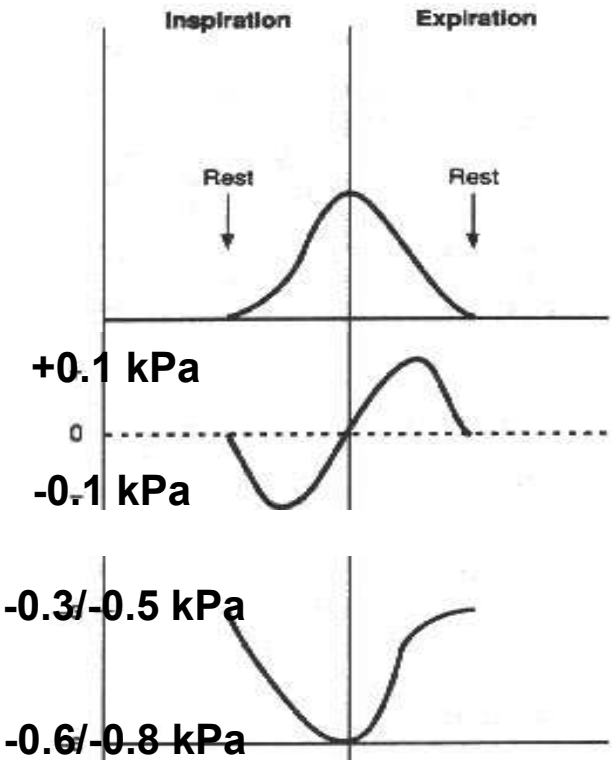

PLEURA
pulmonalis
parietalis


Inspiration
Expiration
Rest
Rest
+0.1 kPa
0
-0.1 kPa
-0.3/-0.5 kPa
-0.6/-0.8 kPa

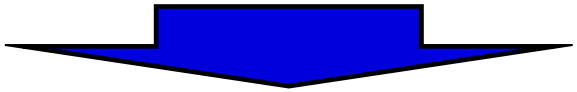
A46: Compliance of lungs. Respiratory work. Pneumothorax

- According to etiology:
  - **traumatic** pneumothorax (due to an injury) occurs if the chest wall is perforated or during an injury of the esophagus, bronchi, and during rib fractures.
  - **spontaneous** pneumothorax
  - **primary** idiopathic pneumothorax (without any known cause) may occur in tall healthy young men with an incidence of pneumothoraxes in the family,
  - **secondary** pneumothorax arises as a consequence of lung diseases (such as COPD or cystic fibrosis),
  - **iatrogenic** pneumothorax (due to medical procedures) occurs during invasive medical examinations such as transparietal aspiration biopsy, subclavian vein catheterization, or mechanical ventilation with positive pressure.
  - **artificially induced** (deliberate) pneumothorax is used during thoracoscopy, an endoscopic examination the thoracic cavity.
- According to the communication of the pleural space with its surroundings
  - **open pneumothorax** (when the hole in the pleural space remains open, the air in the pleural cavity moves back and forth with each breath of the patient)
  - **closed pneumothorax** (when a small opening through which air enters the pleural cavity closes)
  - **valvular pneumothorax** (the tissue of the lungs or the chest wall covers the hole in such a way that a valve emerges, this valve allows air to flow inside during inspiration, but it prevents the air from leaving the pleural cavity during exhalation).

A46: Compliance of lungs. Respiratory work. Pneumothorax

Respiratory system resistance

- Elastic resistance:
  - elastic fibers
  - alveolar surface tension
- Nonelastic resistance:
  - viskose resistance
  - airway resistance



Respiratory work:

- Elastic
- Viskose
- Work of airway resistance

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FORCES PARTICIPATING IN RESPIRATION

- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES represented by:**
  - lungs elasticity
  - chest elasticity

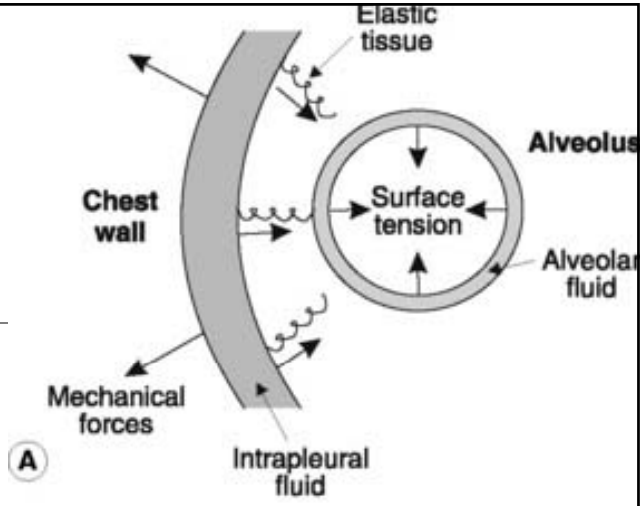
QUIET RESPIRATION

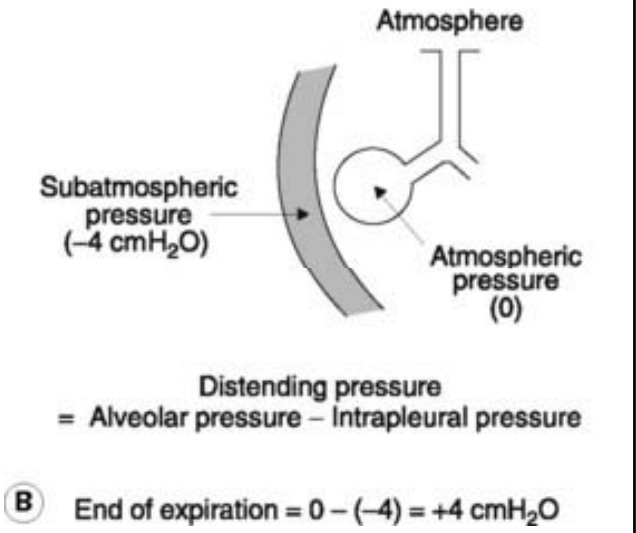
INSPIRATION - active forces of inspiratory muscles prevail

EXPIRATION - only passive (elastic) forces are in action

Forces acting on the lung

1. elasticity of lung (elastic recoil) (collapsing force)
2. Lung surface tension (collapsing force)
3. Chest wall recoil (opening force)
4. Intrapleural pressure-IPP (opening force)





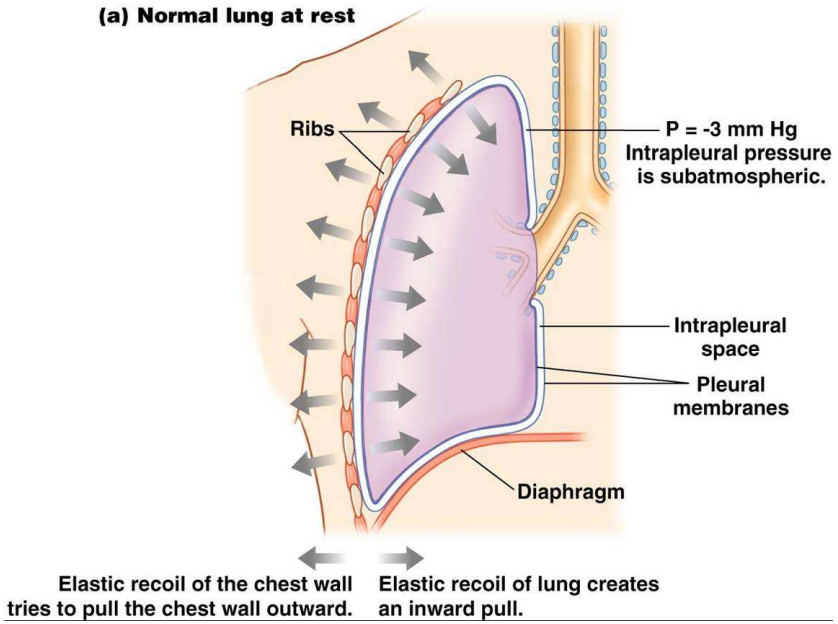
Lung recoil and chest wall recoil

Lung Recoil

- Represents the inward force created by the elastic recoil properties of alveoli.
- As the lung expands, recoil increases; as the lung gets smaller, recoil decreases.
- Recoil, as a force, always acts to collapse the lung.

Chest Wall Recoil

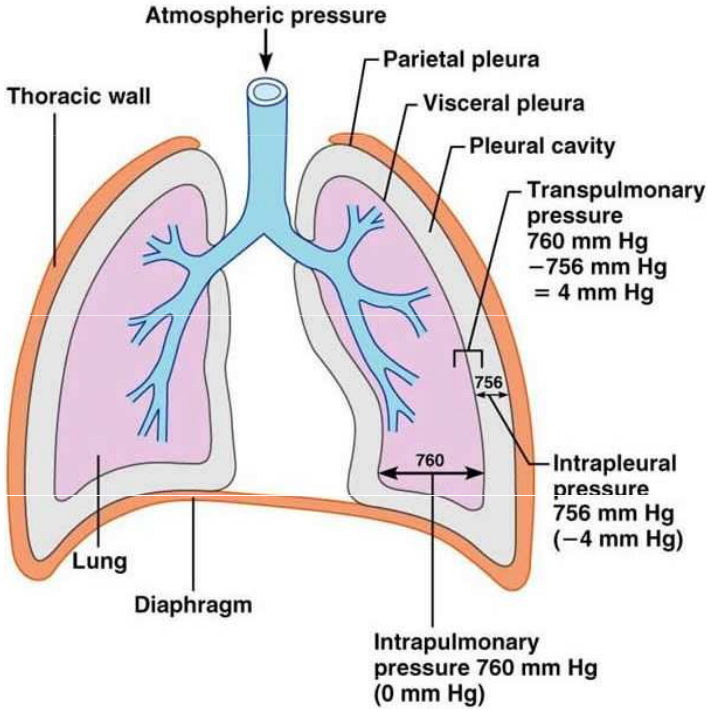
- Outward force of the chest wall
- FRC represents the point where this outward recoil of the chest wall is counterbalanced by the inward recoil of the lung.



Intrapleural pressure

Intrapleural Pressure (IPP)

- Represents the pressure inside the thin film of fluid between the visceral pleura, which is attached to the lung, and the parietal pleura, which is attached to the chest wall.
- The outward recoil of the chest and inward recoil of the lung create a negative (subatmospheric) IPP.
- IPP is the outside pressure for all structures inside the chest wall.



Major forces acting on the lung

Important points

- Intrapleural pressure > Lung recoil → **Lung Expands**
- Intapleural pressure < lung recoil → **lung collapse**
- Intrapleural pressure = Lung recoil → **lung size constant**

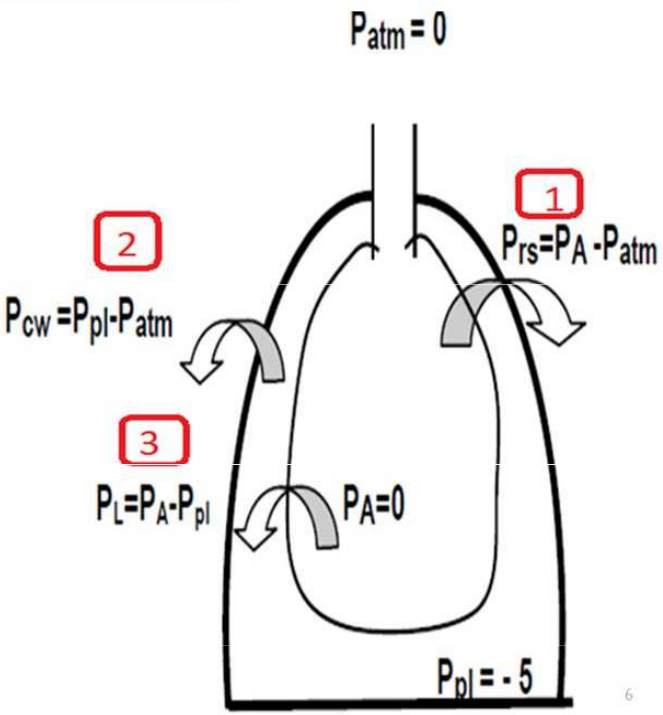
Transmural pressure

BIOPHYSICS OF BREATHING

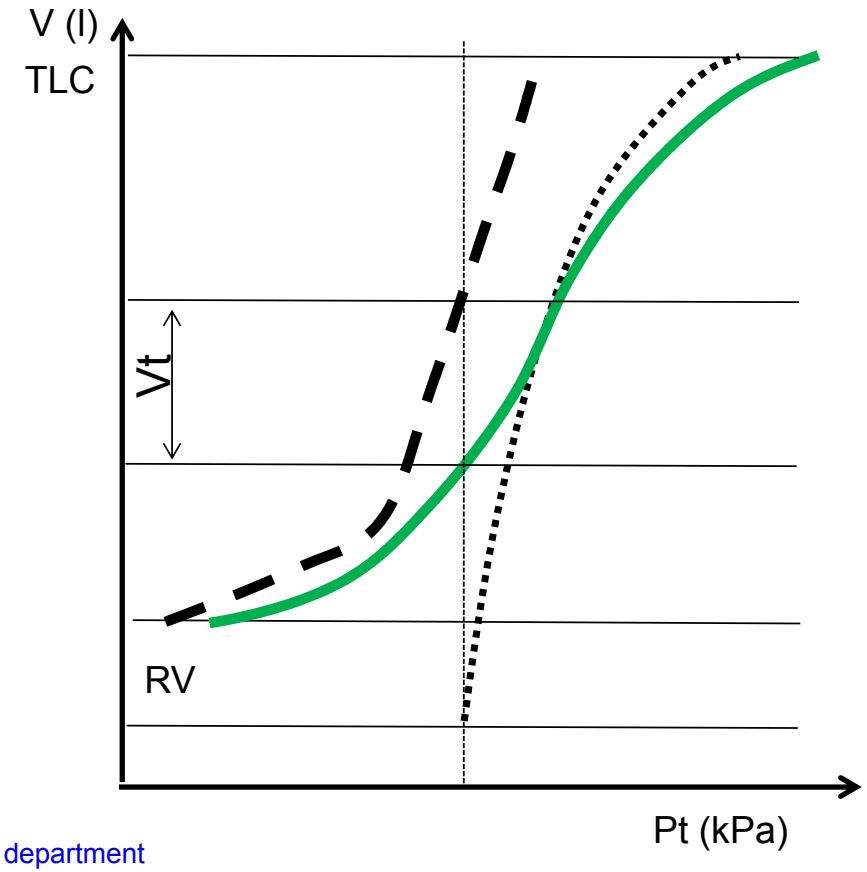
1. Transthoracic (P_{tt}) - difference between alveolar pressure and body surface pressure
(P_{tt}) = (P_{alv}) - (P_{atml})

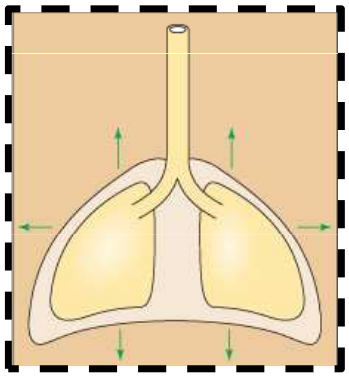
2 . Transchest pressure (P_{ta})- tdifference between the alveoli pressure (P_{alv}) and atmospheric pressure (P_{cw}).= P_{pl}- P_{atm}

3. Transpulmonary pressure (P_{tp}) - difference between the alveolar pressure and the pleural pressure
(P_{tp}) = (P_{alv}) - (P_{pl})

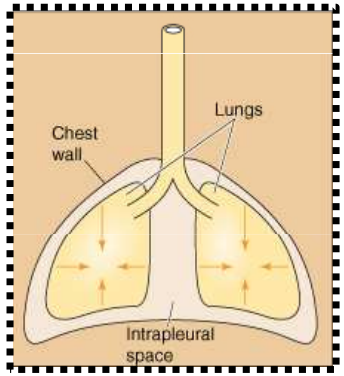


A46: Compliance of lungs. Respiratory work. Pneumothorax

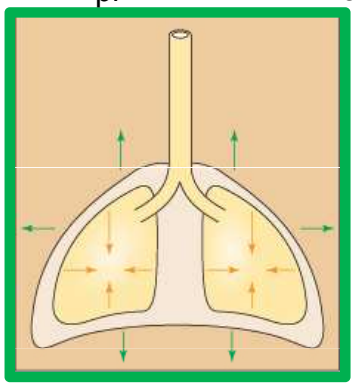




Pt: P_{atm} and P_{pl}



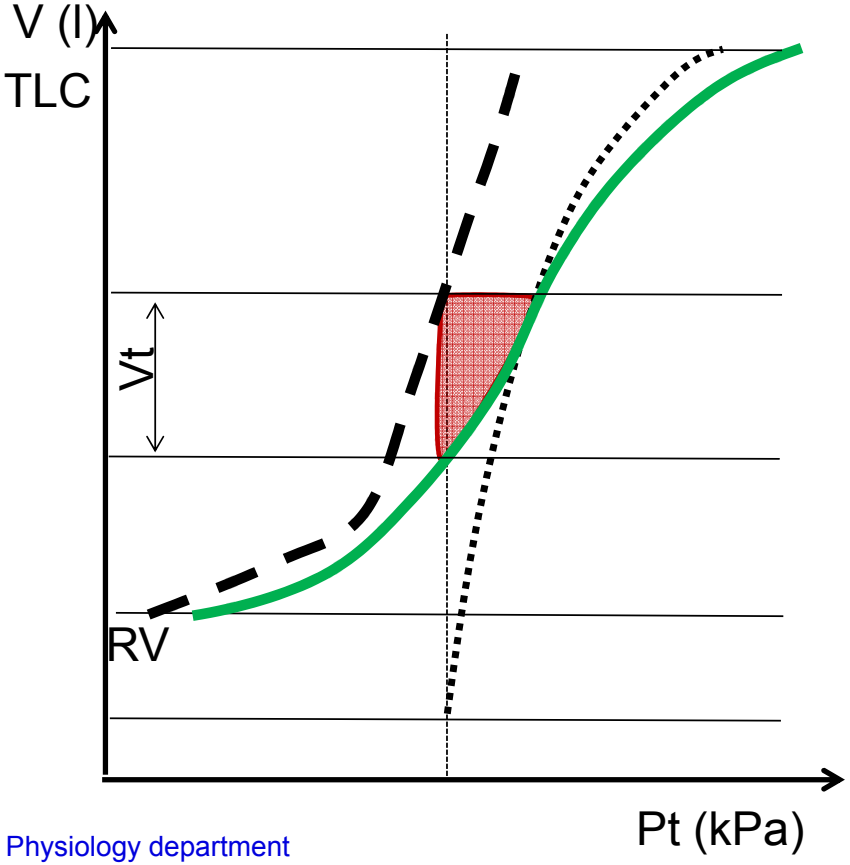
Pt: P_{alv} and P_{pl}

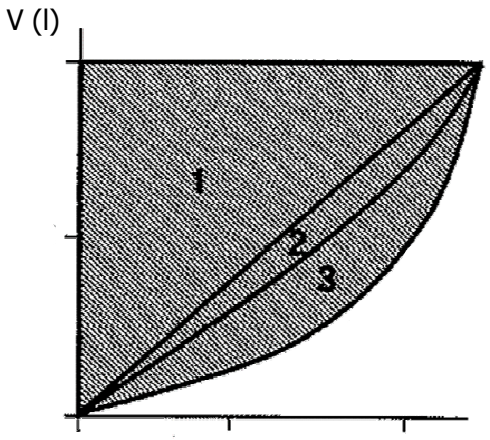


Pt: P_{atm} and P_{alv}

MUNI MED

A46: Compliance of lungs. Respiratory work. Pneumothorax





Respiratory work:
1 – elastic
2 – viscos
3 – airway resistance

MUNI MED

A47: Composition of atmospheric and alveolar air. Gas exchange in lungs and tissues.

COMPOSITION OF DRY ATMOSPHERIC AIR

O_2	20.95 %	$F_{O2} \cong 0,21$
N_2	78.09 %	$F_{N2} \cong 0,78$
CO_2	0.03 %	$F_{CO2} \cong 0,0004$

BAROMETRIC PRESSURE IN SEA LEVEL
1 atmosphere = 760 mm Hg

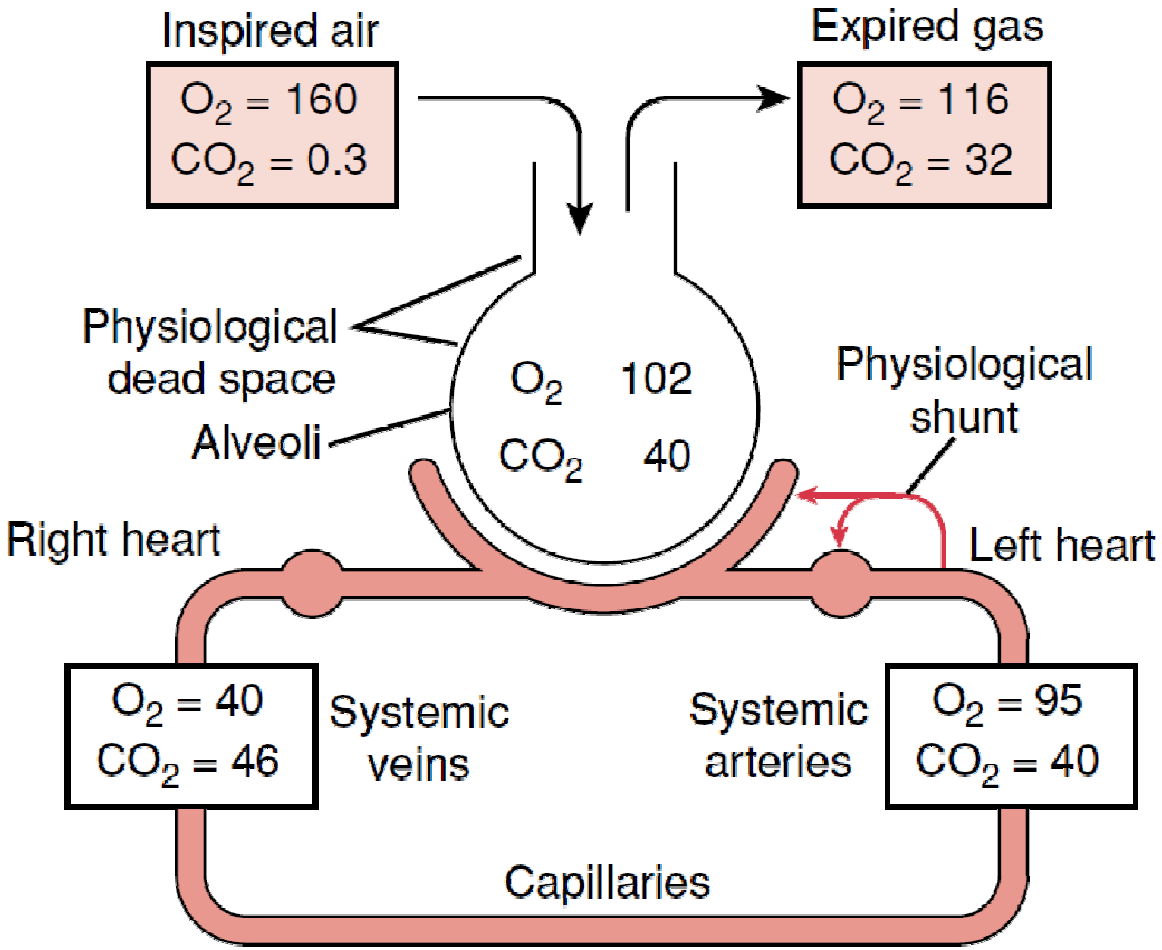
PARTIAL PRESSURE OF DRY AIR IN SEA LEVEL

P_{O2}	= 760 x 0,21	=	~160 mm Hg
P_{N2}	= 760 x 0,78	=	~593 mm Hg
P_{CO2}	= 760 x 0,0004	=	~ 0,3 mm Hg

 1 *kPa* = 7,5 *mm Hg (torr)*

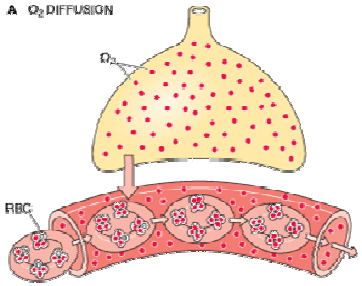
MUNI MED

A47: Composition of atmospheric and alveolar air. Gas exchange in lungs and tissues.



MUNI MED

A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2



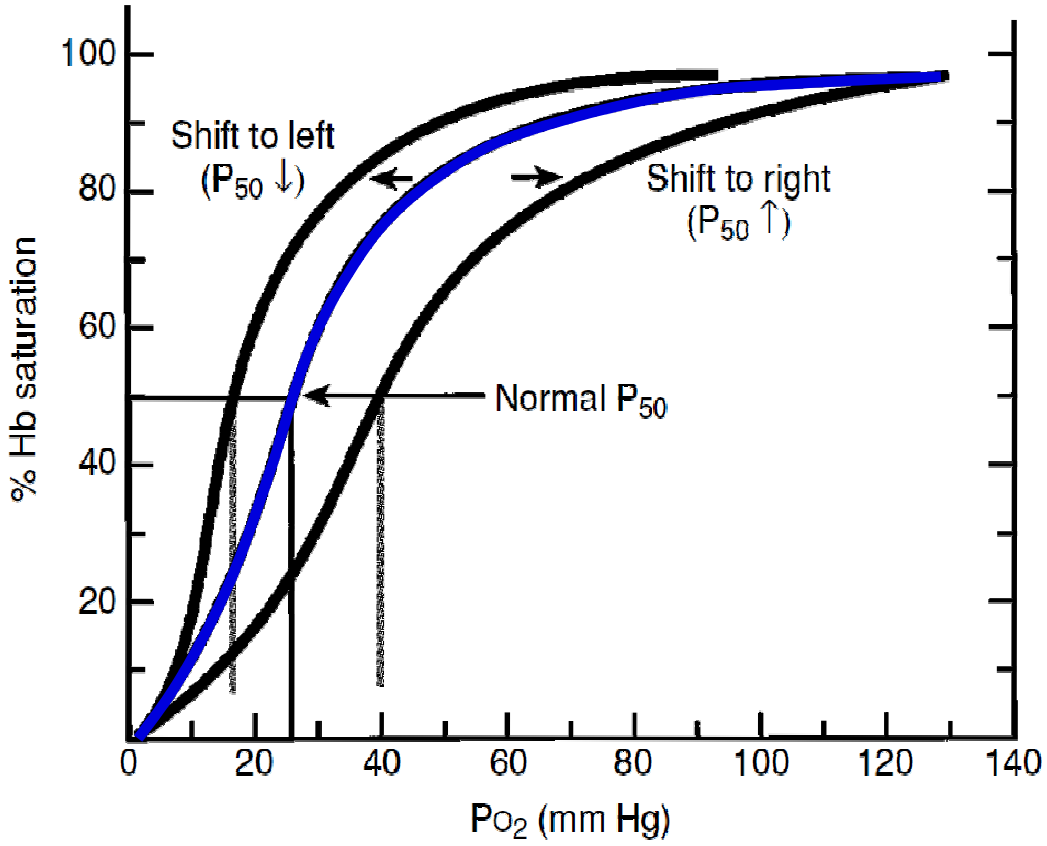
O_2 is transported in two forms :

- physically dissolved(1%)
- in chemical bond with Hb (99%)

- Fetal hemoglobin(2α, 2γ)
- Methemoglobin (Fe^{3+})
- Carboxyhemoglobin (CO)
- Carbaminohemoglobin (CO_2)
- Oxyhemoglobin (O_2)
- Deoxyhemoglobin (without any gases)

MUNI MED

A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2

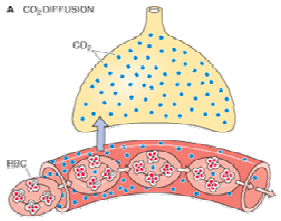


Dissociation curve of Hb is influenced by:

- pH of blood
- pCO_2 of blood
- Temperature
- Concentration of 2,3 - BPG

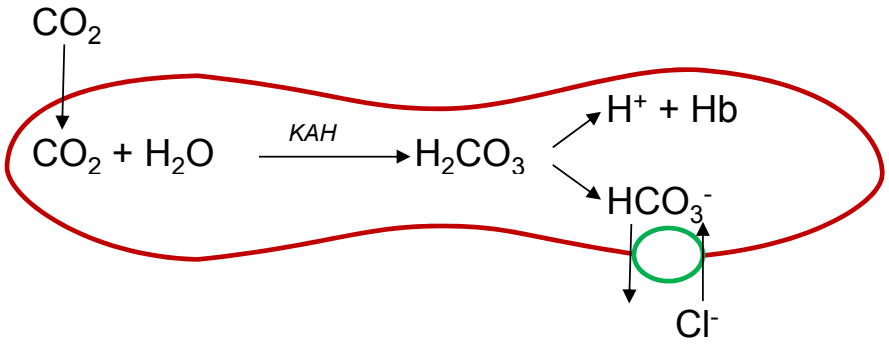
MUNI MED

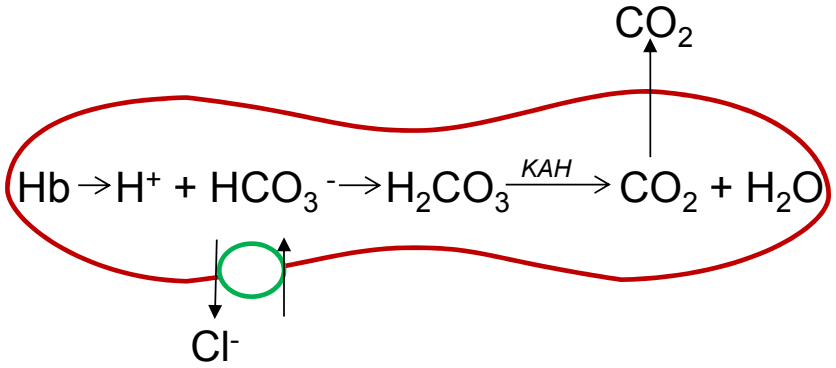
A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2



CO_2 is transported in next forms :

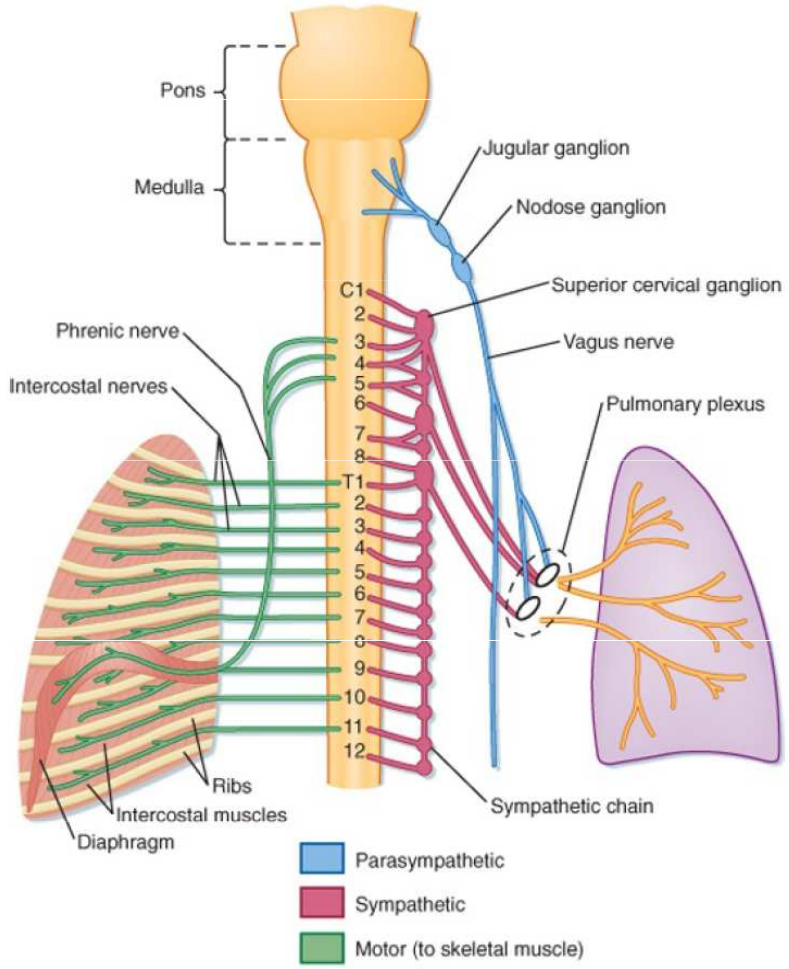
- physically dissolved(5 %)
- in the form of bicarbonate anions (85%)
- in chemical bond with Hb (10%)





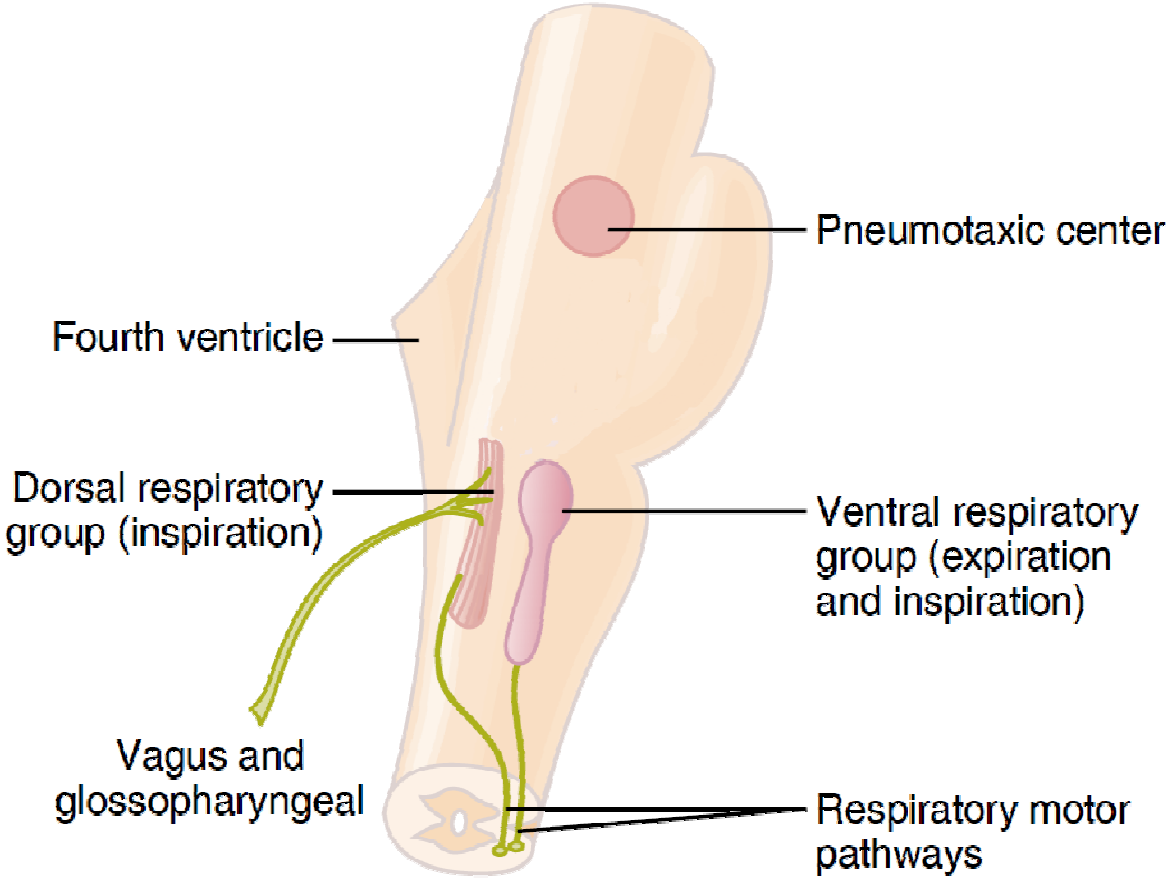
MUNI MED

A49: Regulation of ventilation



MUNI MED

A49: Regulation of ventilation



MUNI MED

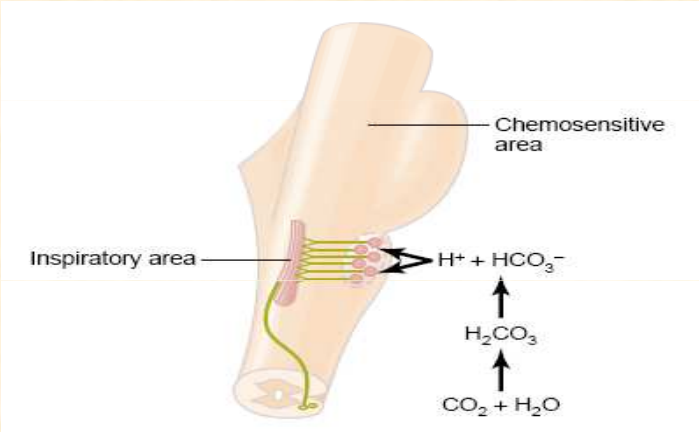
- They can be divided into three **main groups:**
  - *dorsal respiratory group* – placed bilaterally on the dorsal side of the medulla oblongata, only inspiratory neurons, sending axons to motoneurons of inspiratory muscles (diaphragm, external intercostal muscles; their activation=inspiration, their relaxation=expiration; participates on inspiration at rest and forced inspiration
  - *ventral respiratory group* - located on the ventrolateral part of the medulla oblongata, the upper part: neurons whose axons of motor neurons activate the main and auxiliary inspiratory muscles; the lower part: expiratory neurons which innervate expiratory muscles (internal intercostal muscles). Neurons in this group operate only during forced inspiration and forced expiration.
  - *Pontine respiratory group* *- pneumotaxic center -* dorsally placed on top of the pont, contributes to the frequency and depth of breathing; affects the activity of respiratory neurons in the medulla oblongata.

Chemical factors affecting the respiratory center:

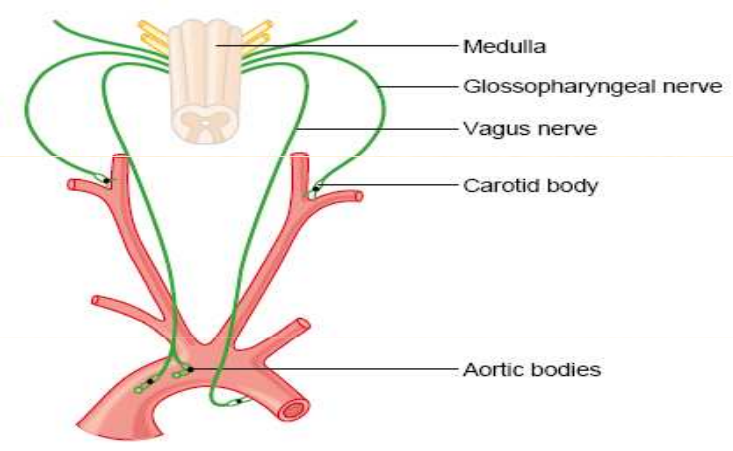
Central chemoreceptors

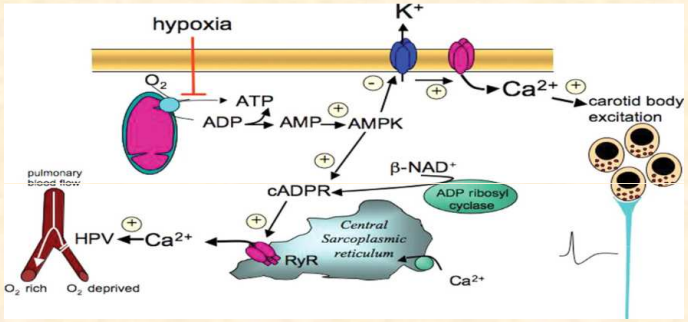
- on the front side of the medulla
- sensitive only to increase of arterial pCO_2 (by increasing H^+

(intracerebral fluid)



- Notice:
- central chemoreceptor are stimulated by other types of acidosis (lactate acidosis, ketoacidosis)





Peripheral chemoreceptors

– located in the aortic and carotid bodies

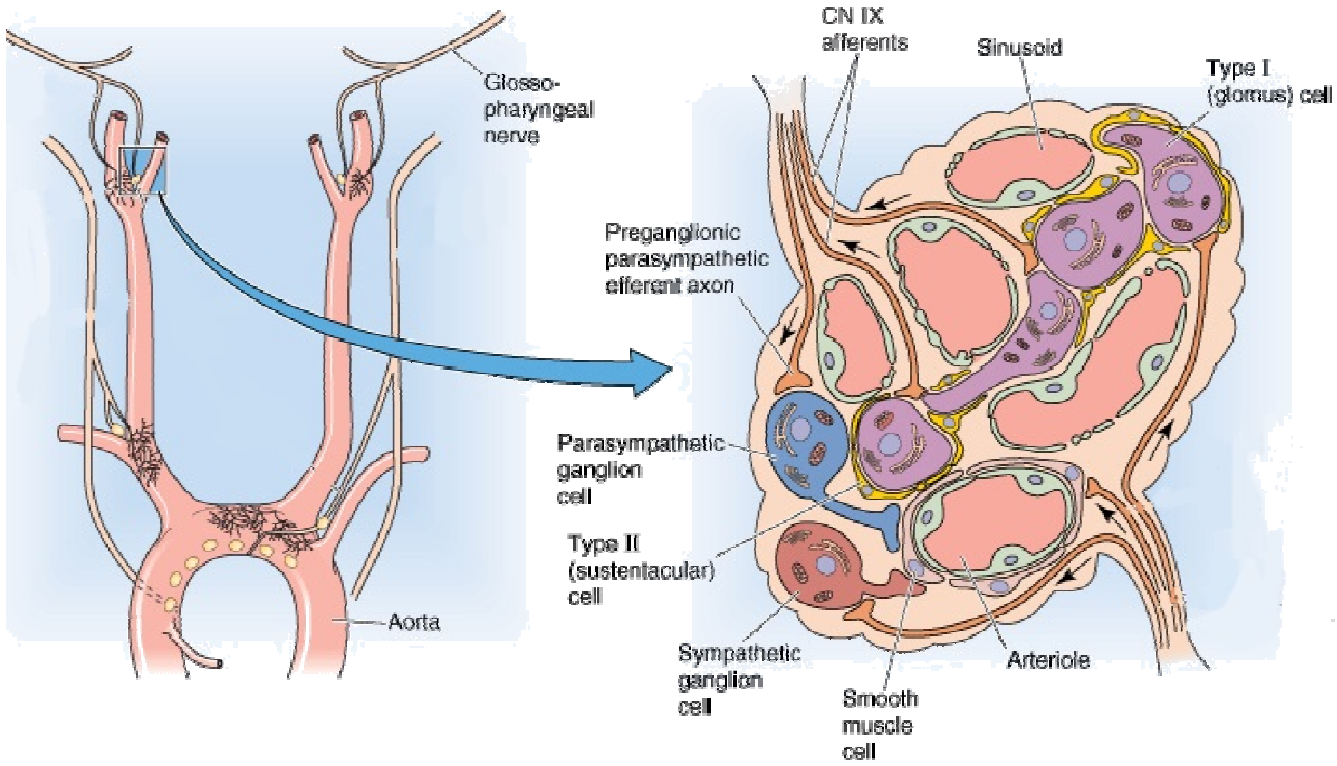
-primarily sensitive to decrease in arterial pO_2, particularly to decrease of O_2 under 10-13 kPa in the arterial blood.

They convey their sensory information to the medulla via the vagus nerve and glossopharyngeal nerve.

Mechanism of action: Decreased ATP production in mitochondria leads to depolarization of receptors membrane and to excitation of chemoreceptor

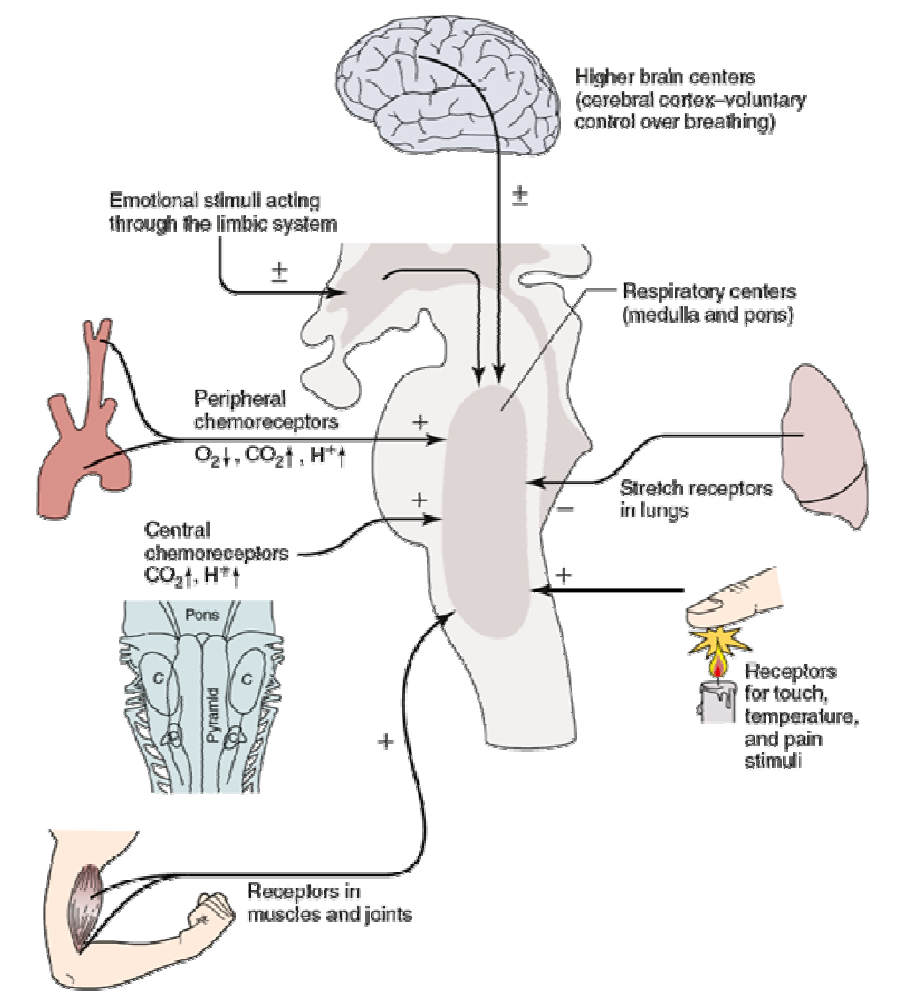
http://www.medicine.mcgill.ca/physio/resp-web/sect8.htm,

A49: Regulation of ventilation



MUNI
MED

A49: Regulation of ventilation



MUNI
MED

A50: Respiratory responses to irritants

The lungs are protected from damage by:

- presence of hair (vibrissae) in the nasal cavity (traps dust particles)
- presence of ciliary epithelium covered with mucus (cilia moving mucus in one direction - into the pharynx)
- pulmonary alveolar macrophages
- presence of antibodies in bronchial secretion (IgA)

Reflexes:

- Herring-Breuer reflexes (inflation/deflation)
- Sneeze reflex
- Cough reflex
- Hiccup
- Yawn

A50: Respiratory responses to irritants

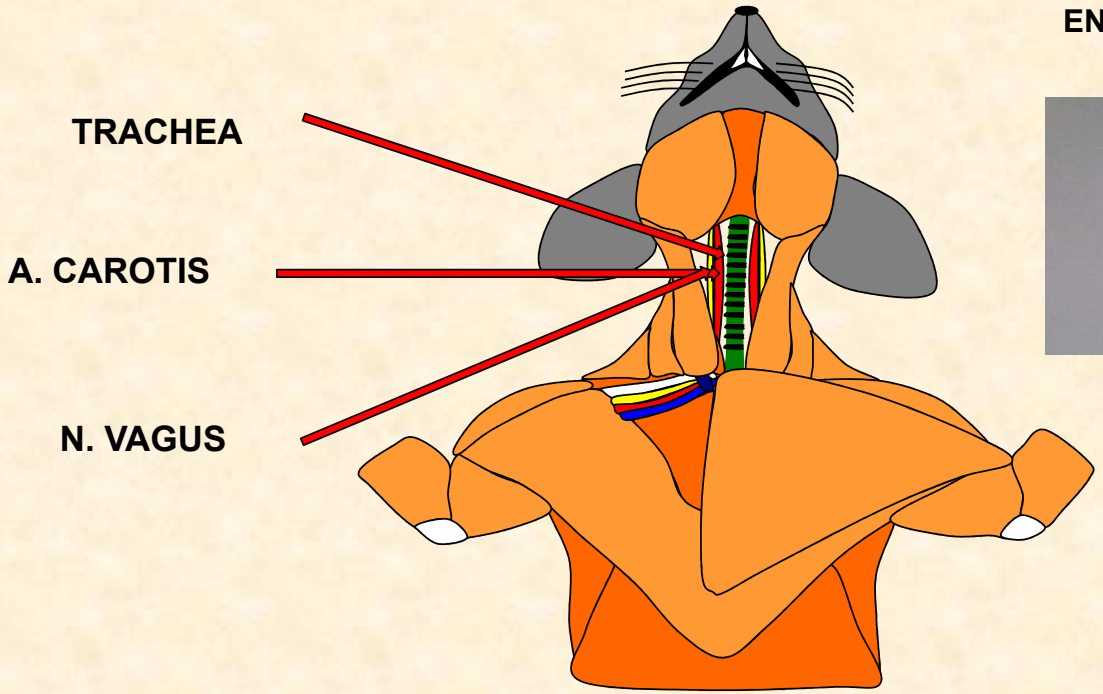
Cough Reflex	Sneeze Reflex	Hiccup
Cough is an expulsive reflex that protects the lungs and respiratory passage from foreign bodies. *Causes of cough*: – Irritants-smokes, fumes, dusts, etc. – Diseased conditions like COPD, tumors of thorax, etc. *Pathway for cough reflex:* – Receptors in nose, paranasal sinuses, pharynx, trachea, pleura, diaphragm, perichondrium, stomach, ex.auditory canal and tymphanic membrane – V,IX,X cranial nerves and phrenic nerves – medulla – X cranial nerve, phrenic nerve, spinal motor nerve – primary and accessory respiratory muscles	Sneeze is defined as the involuntary expulsion of air containing irritants from nose. *Causes of sneeze:* – Irritation of nasal mucosa – Excess fluid in airway *Pathway for sneeze reflex:* – Olfactory receptors or V cranial nerve endings – I and V cranial nerve – medulla – nucleus solitarious and reticular formation – V, VII, IX, X cranial nerves and intercostal muscles – pharyngeal, tracheal and respiratory muscles	Hiccup is spasmodic contraction of the diaphragm which causes a sudden intake of breath that is involuntarily cut off by closure of the glottis, thus producing a characteristic sound. *Causes of hiccup:* – Eating too fast or too much – Strokes, brain tumors, damage to the vagus or phrenic nerve – Anxiety and stress *Pathway for sneeze reflex:* – Phrenic, vagus, and sympathetic nerves – Midbrain – Motor fibers of phrenic nerve and accessory nerves – Diaphragm and intercostal muscles

A50: Respiratory responses to irritants

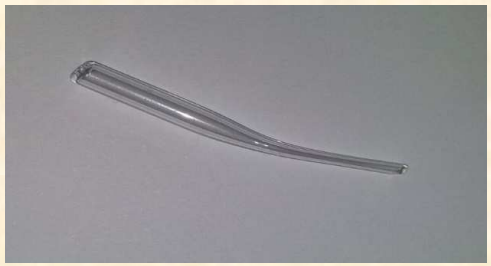
Herring-Breuer reflexes (inflation/deflation)

- *a. keeps the lungs from over-inflating with inspired air*
  - *pulmonary stretch R – vagus nerve – medulla – inhibition of inspiration and initiation of expiration*
- *b. serves to shorten exhalation when the lung is deflated*
  - *pulmonary stretch R – vagus nerve – the pontine center*

- Hering – Breuer ´s reflex in animal experimentH

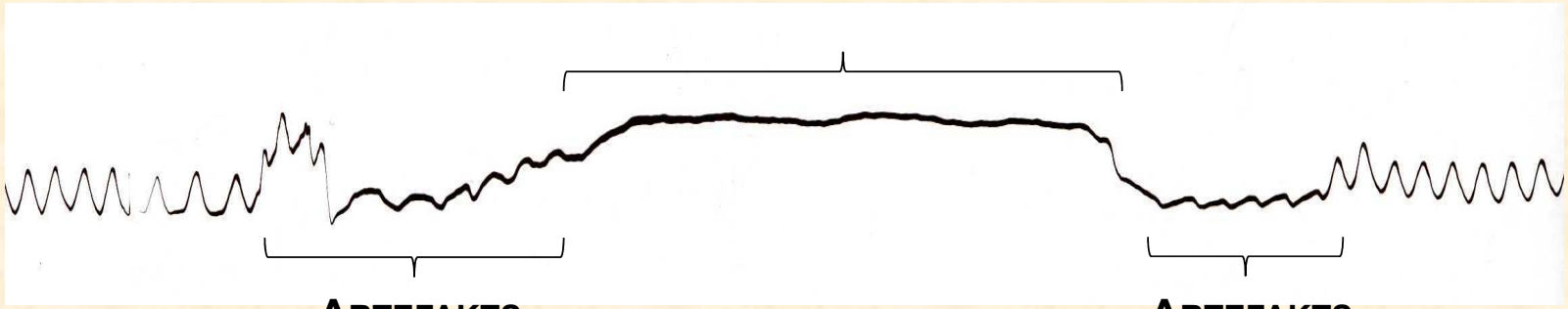


ENDOTRACHEAL CANNULA



HERING-BREUER REFLEX

REFLEX STOP BREATHING



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Changes of breathing after VAGOTOMY