Physiology of the respiratory system.

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

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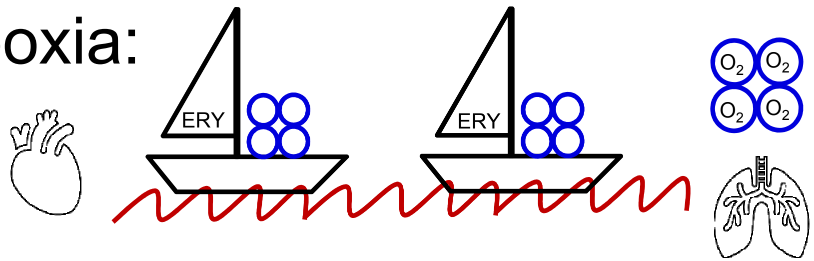
A22: Hypoxia and ischemia

- 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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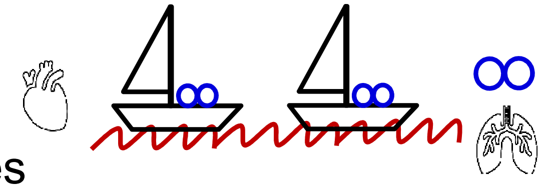
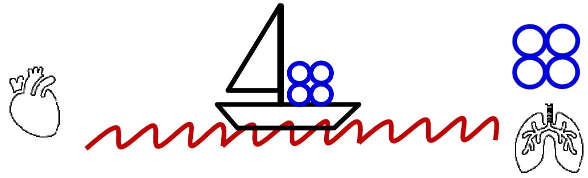
A22: Hypoxia and ischemia

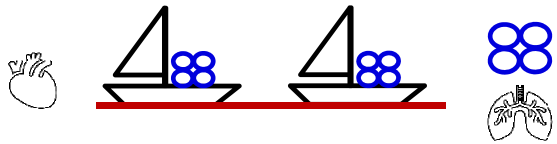
- Hypoxic:
  - physiological: stay at higher altitudes
  - ↓ pO_2; N Ery
  - pathological: hypoventilation during lung or neuromuscular diseases
  - ↓ ventilation; N pO_2; N Ery



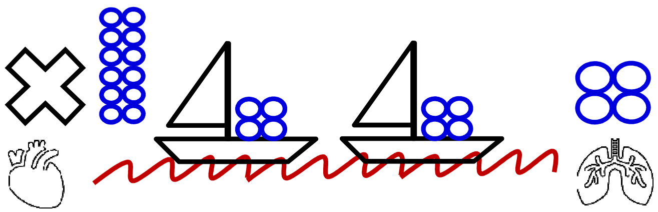
- Transport (anemic):
  - reduced transport capacity of blood for oxygen (anemia, blood loss)
  - N pO_2; ↓ Ery/Hb



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

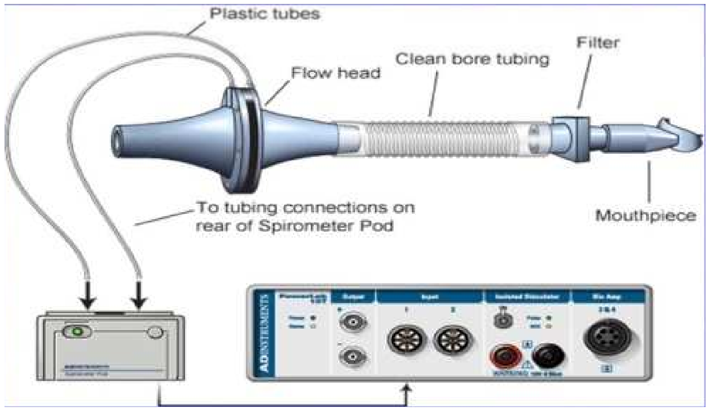


- Histotoxic
  - cells are unable to utilize oxygen (cyanide poisoning)
  - N pO_2; N Ery



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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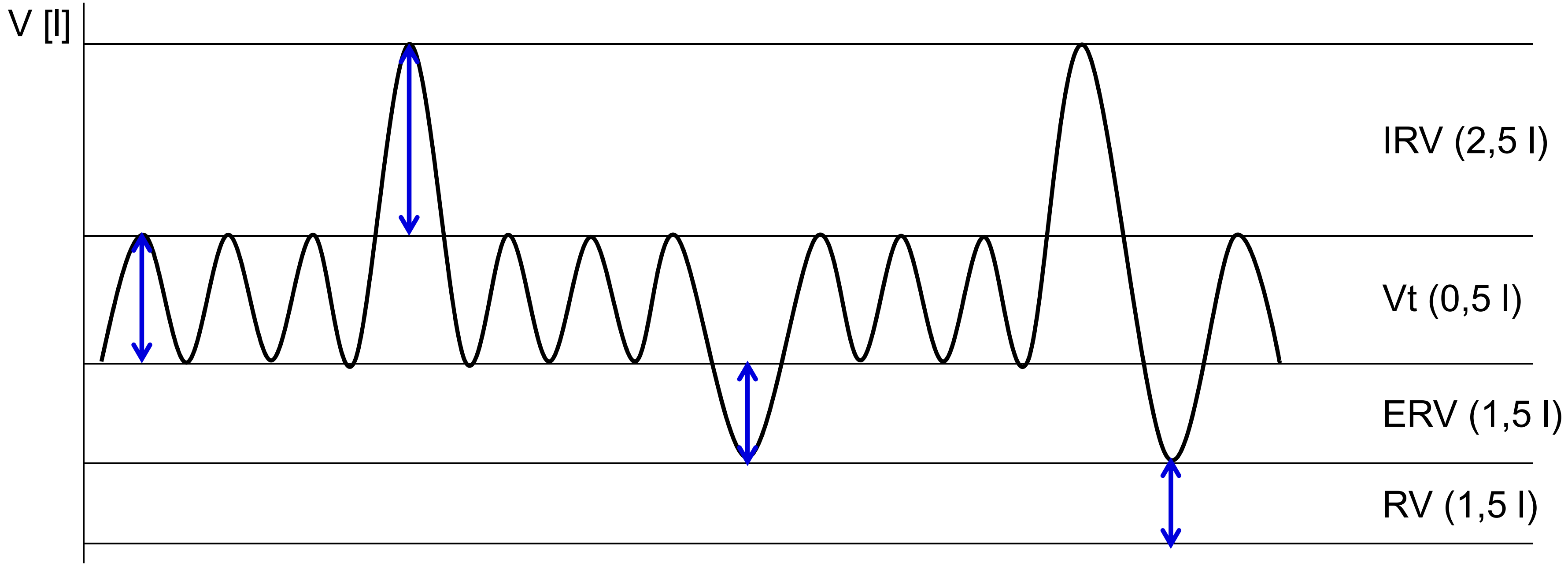
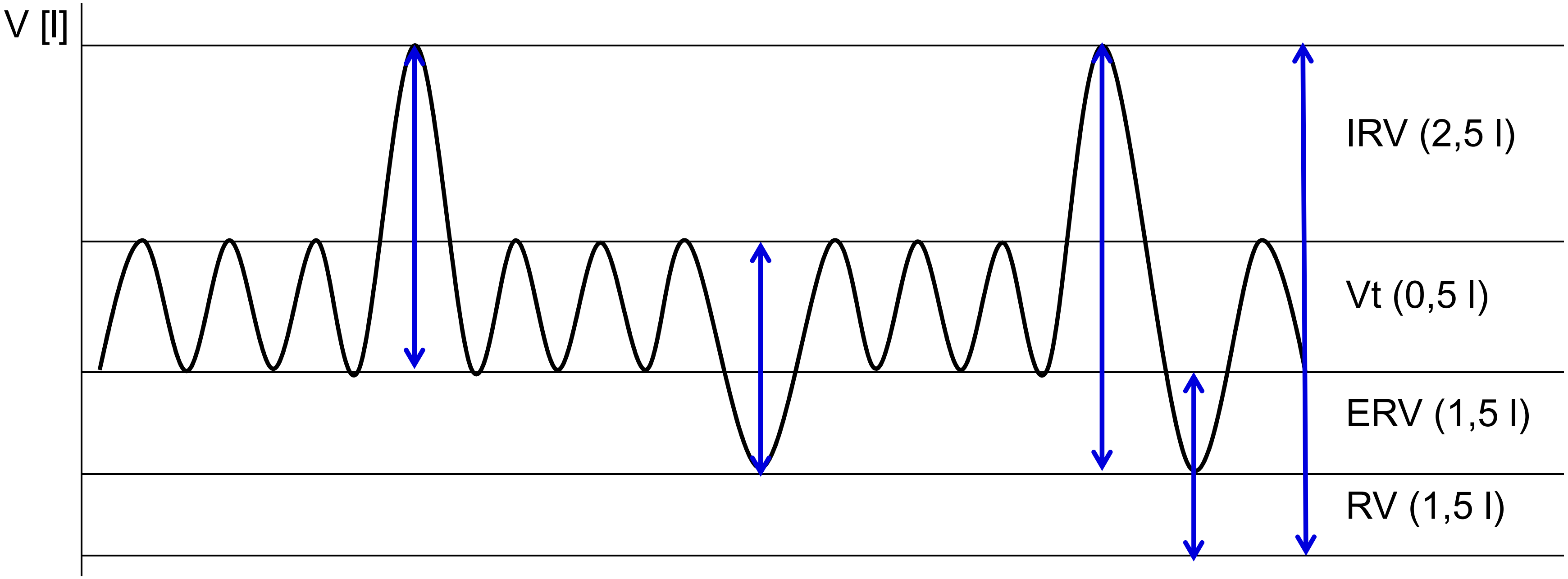
A25: Lung ventilation, volumes, measurement



- ***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.

A25: Lung ventilation, volumes, measurement



Lung capacity:

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

Dynamic lung volumes:

- VE
- MMV

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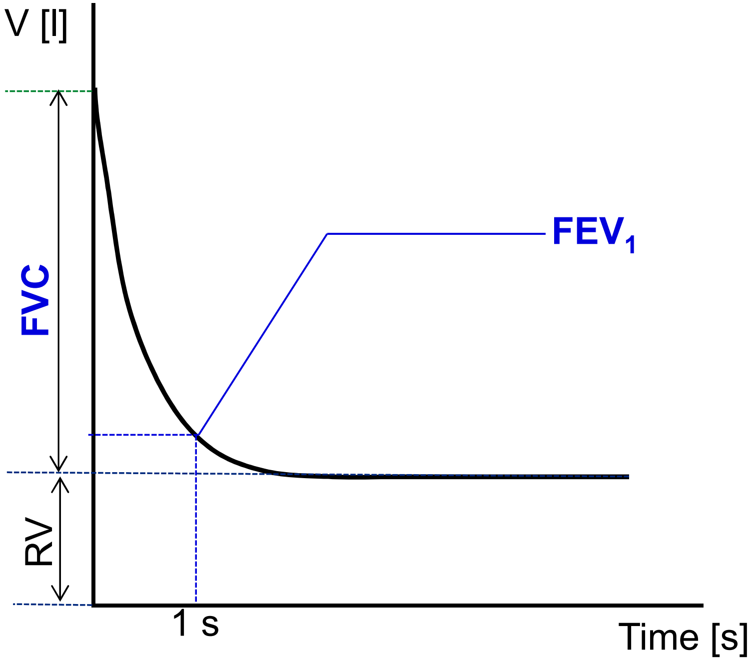
A25: Lung ventilation, volumes, measurement

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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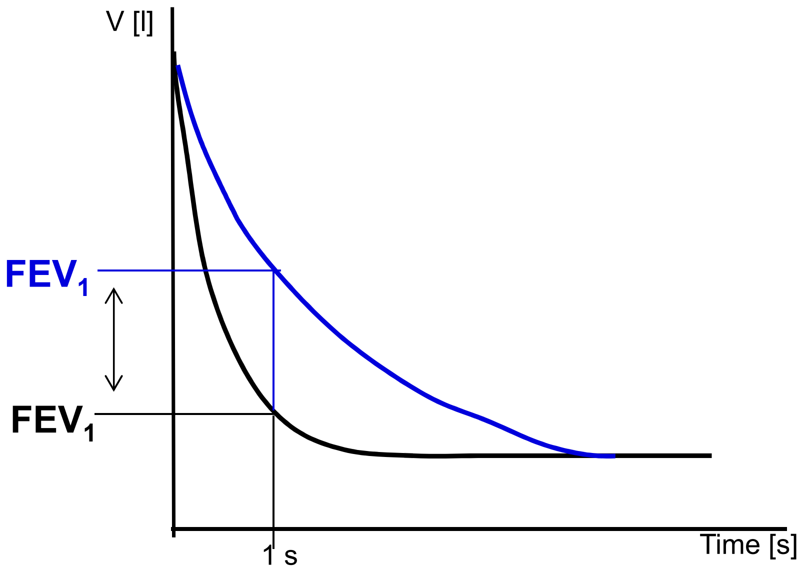
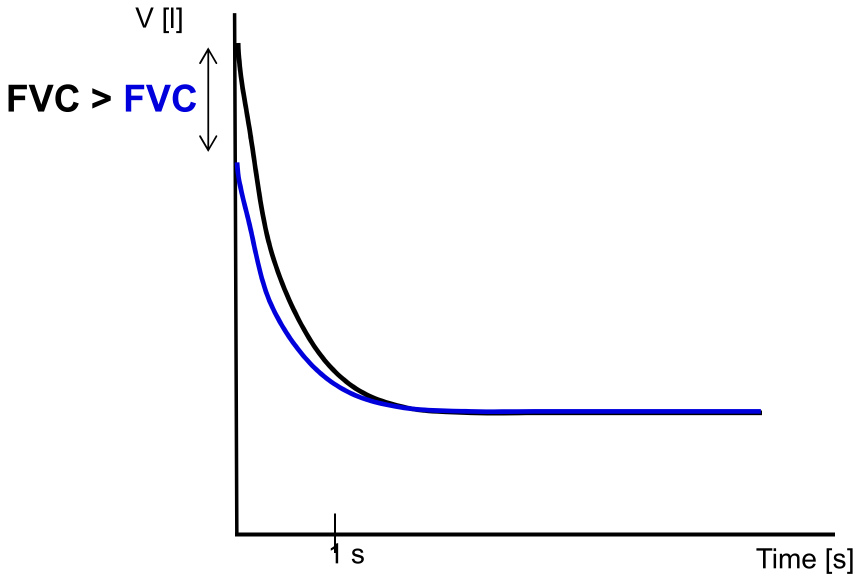
A25: Lung ventilation, volumes, measurement



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

- tracheal stenosis
- astma bronchiale
- CHOPN
- tumor



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

Pulmonarzy etiology

- pulmonary fibrosis
- lung resection
- pulmonary edema
- pneumonia

Extrapulmonary etiology

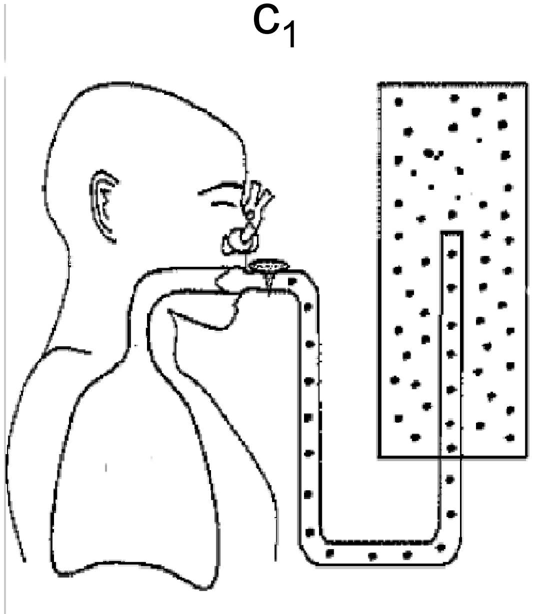
- ascites
- kyphoscoliosis
- burns
- high diaphragm condition

A25: Lung ventilation, volumes, measurement

Helium dilution method – residual volume

V_1

c_1



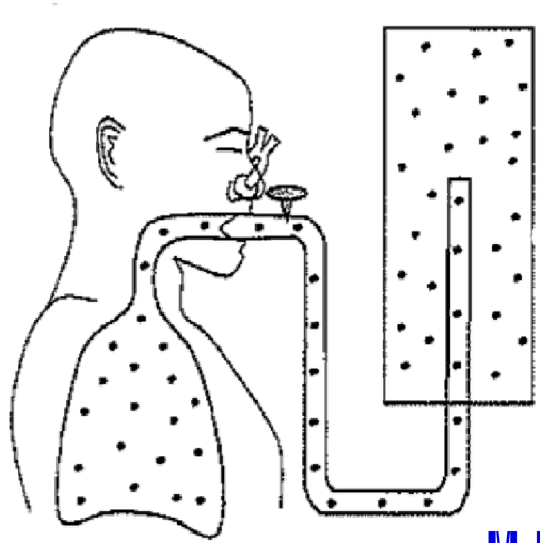
$$c = \frac{n}{V}$$

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

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

$V_2 = RV + V_1$

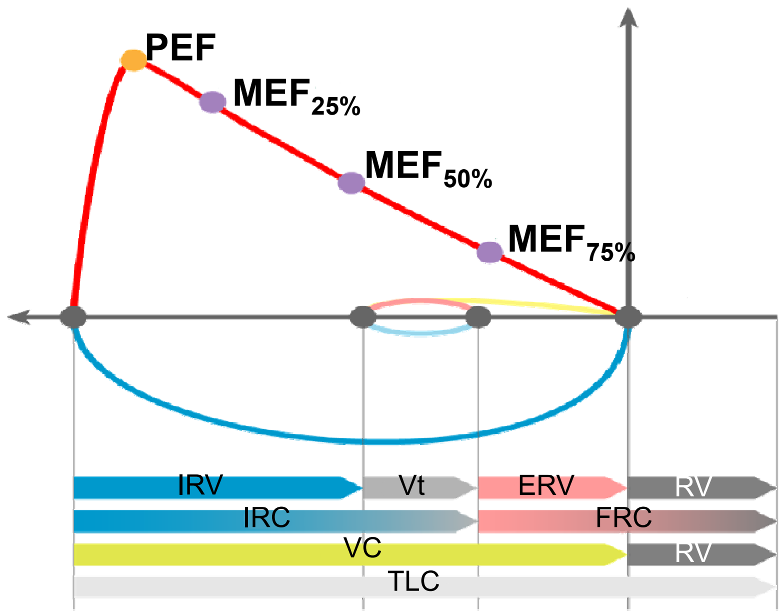
c_2



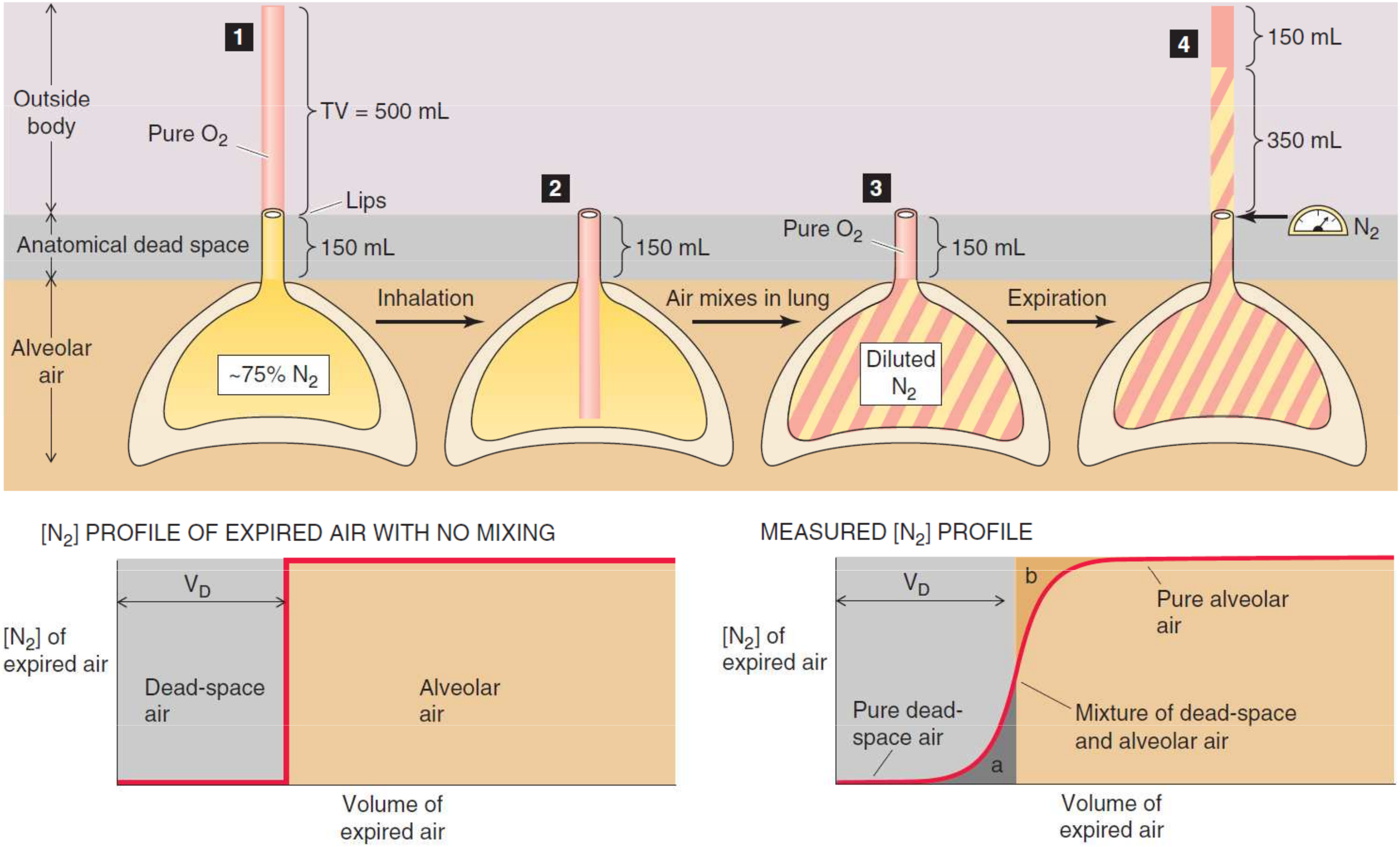
A28: Maximal respiratory flow - volume curve (spirogram)

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)



A26: Dead space, measurement



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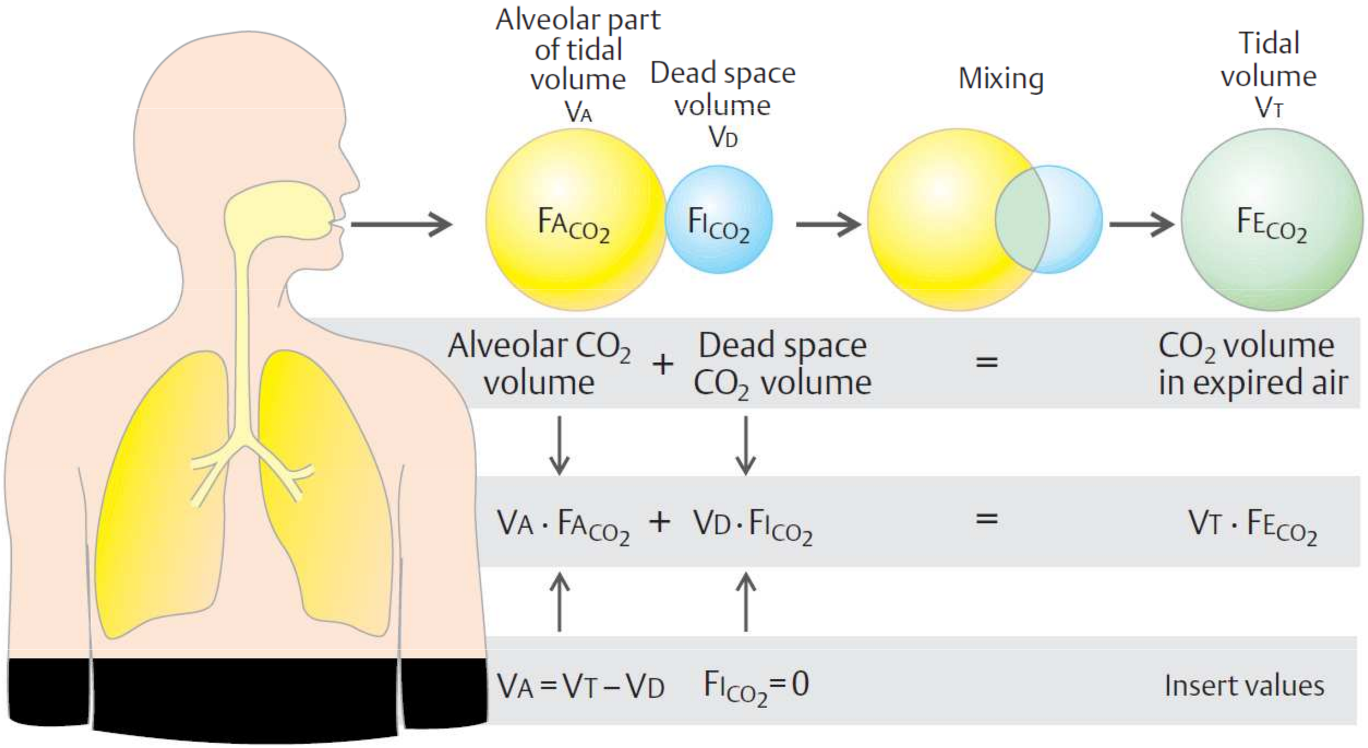
A26: Dead space, measurement



Bohr equation

$$\text{Dead space } V_D = \frac{V_T\,(F_{A_{CO_2}} - F_{E_{CO_2}})}{F_{A_{CO_2}}}$$

Using normal values:

$$V_D = \frac{0.5\,(0.056 - 0.040)}{0.056}$$

Dead space V_D = 143 mL

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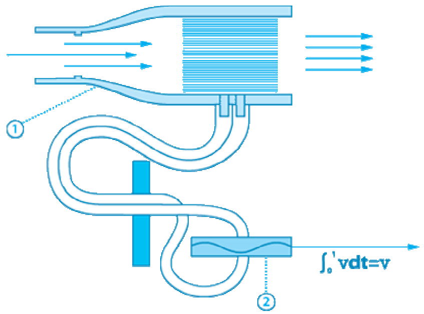
A27: Resistance of airways, measurement

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



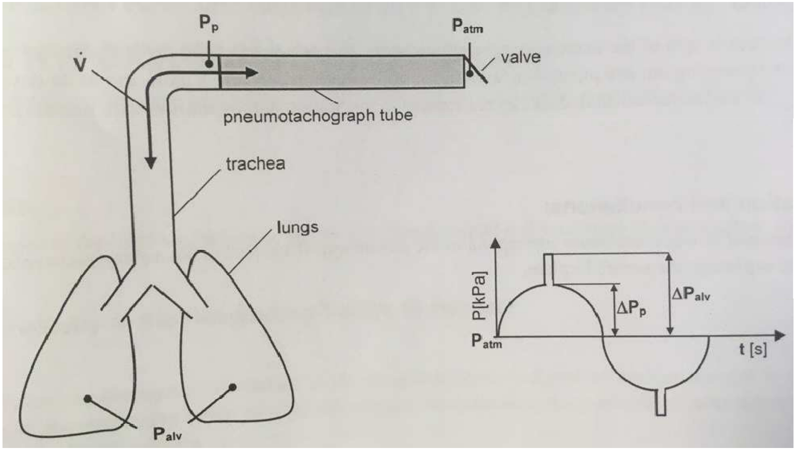
$$\dot{V} = \frac{\Delta P}{R}$$

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

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

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

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



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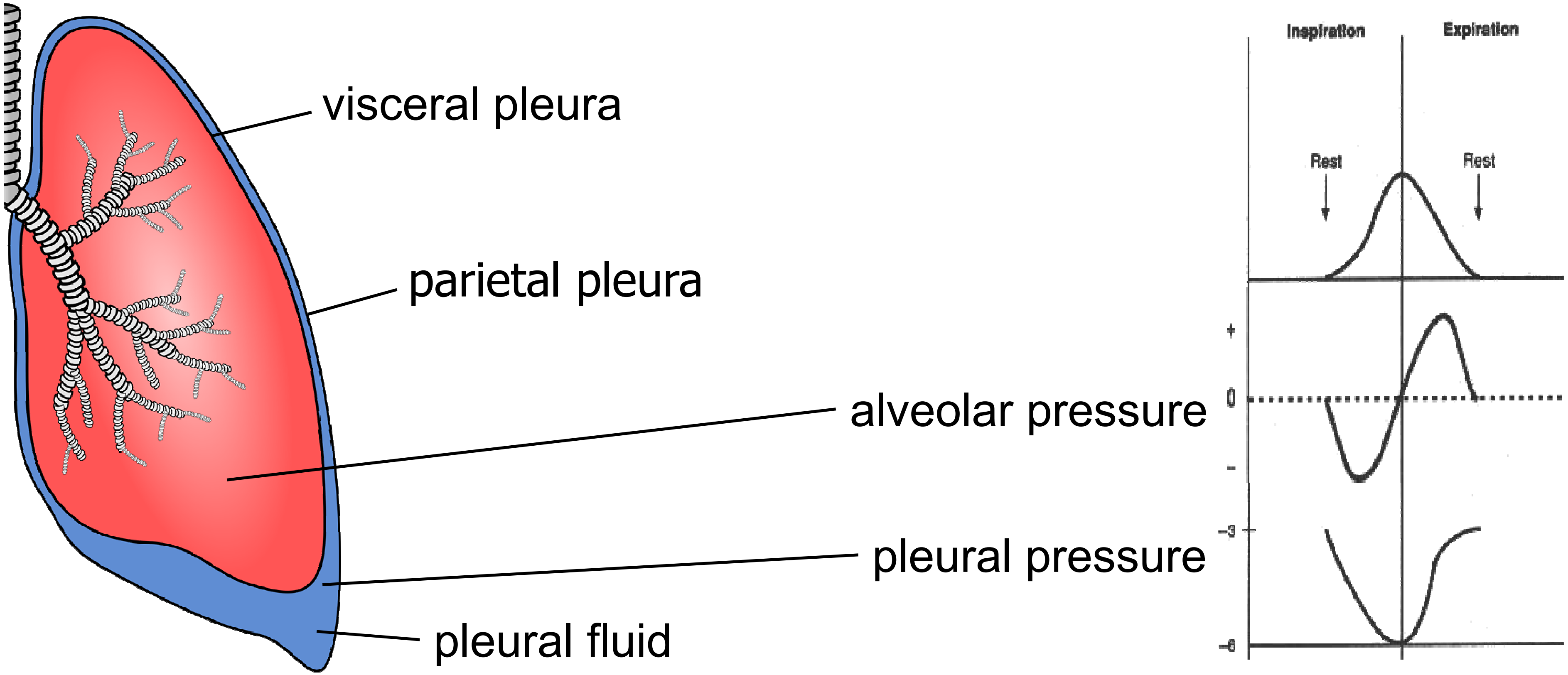
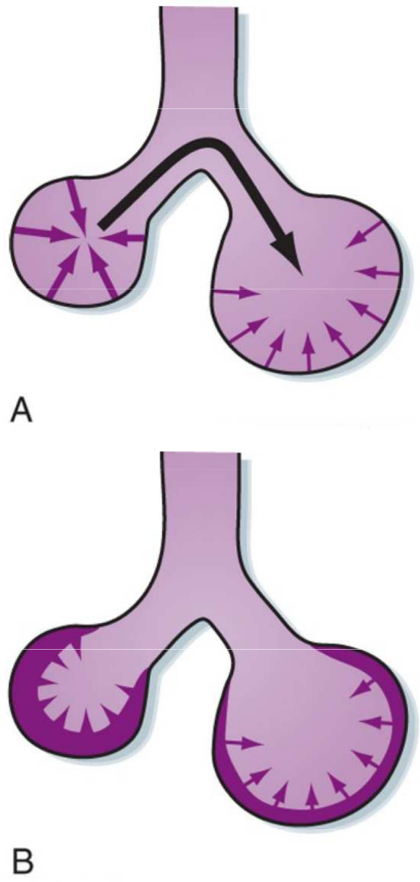
A46: Compliance of lungs. Respiratory work. Pneumothorax



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).

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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A46: Compliance of lungs. Respiratory work. Pneumothorax

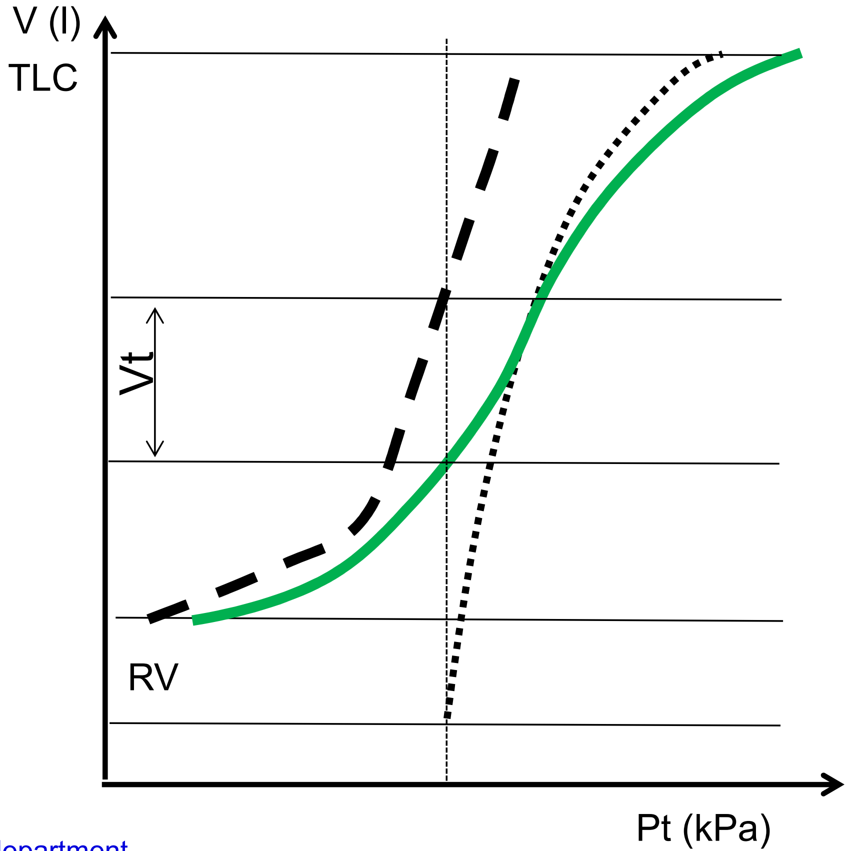
Respiratory system resistance

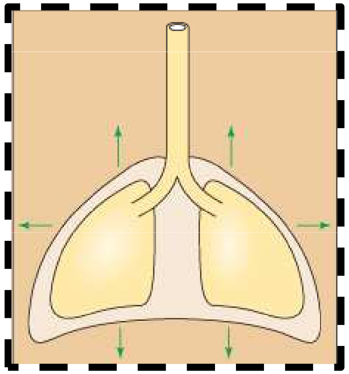
- Elastic resistance:
  - elastic fibers
  - alveolar surface tension
- Nonelastic resistance:
  - viskose resistance
  - airway resistance

Respiratory work:

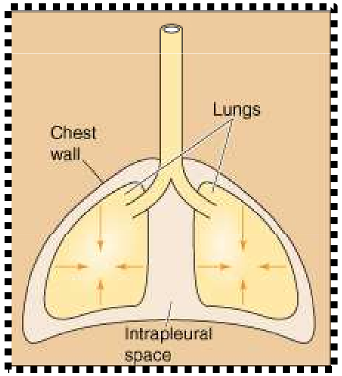
- Elastic
- Viskose
- Work of airway resistance

A46: Compliance of lungs. Respiratory work. Pneumothorax

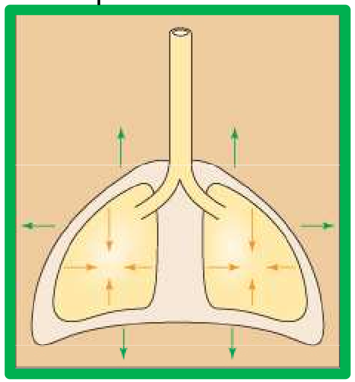




Pt: P_{atm} and P_{pl}



Pt: P_{alv} and P_{pl}



Pt: P_{atm} and P_{alv}

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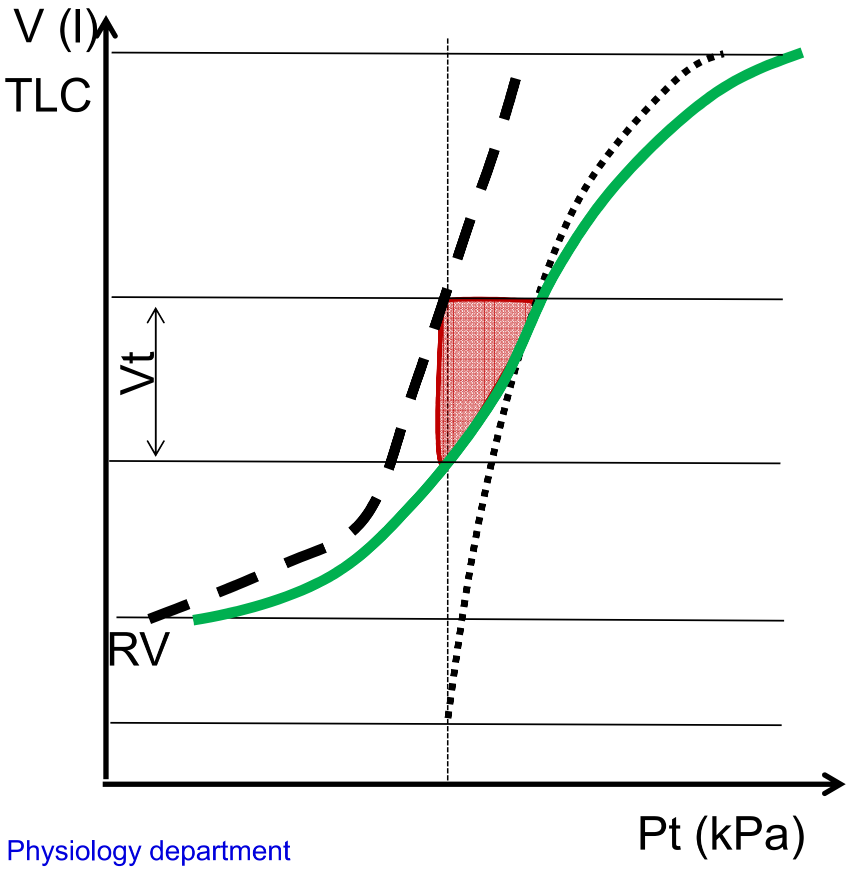
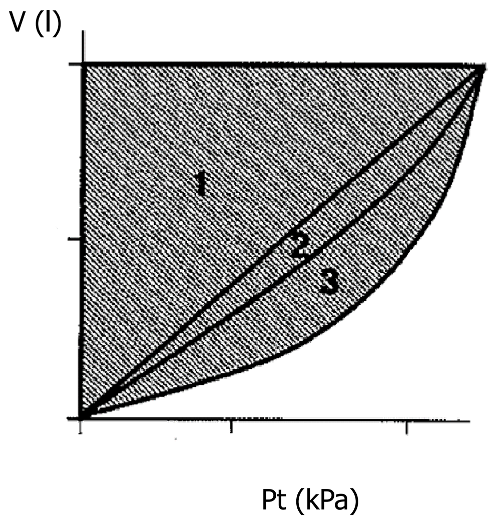
A46: Compliance of lungs. Respiratory work. Pneumothorax





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

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Case report

Herman Neiswander is a 65-year-old retired landscape architect. One cold January morning, he decided to warm his car in the garage. Forty minutes later, Mr. Neiswander's wife found him slumped in the front seat of the car, confused and breathing rapidly. He was taken to a nearby emergency department, where he was diagnosed with acute carbon monoxide (CO) poisoning and given 100% O2 to breathe. An arterial blood sample had an unusual cherry-red color. The values obtained in the blood sample are given in table below.

pO_2	660 mm Hg (normal, 100 mm Hg)
pCO_2	36 mm Hg (normal, 40 mm Hg)
% O_2	50 (normal, 95–100)
Pulse oximetry	100%

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Case report

1. Why was Mr. Neiswander's O2 saturation reduced to 50%?
2. If Mr. Neiswander's % O2 saturation was 50%, why was his pulse oximetry value 100%?
3. What percentage of the heme groups on his hemoglobin were bound to CO?
4. O_2–hemoglobin dissociation curve. What effect did CO poisoning have on the affinity of hemoglobin for O_2?
5. How did CO poisoning alter O2 delivery to Mr. Neiswander's tissues?
6. What was the rationale for giving Mr. Neiswander 100% O2 to breathe?

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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

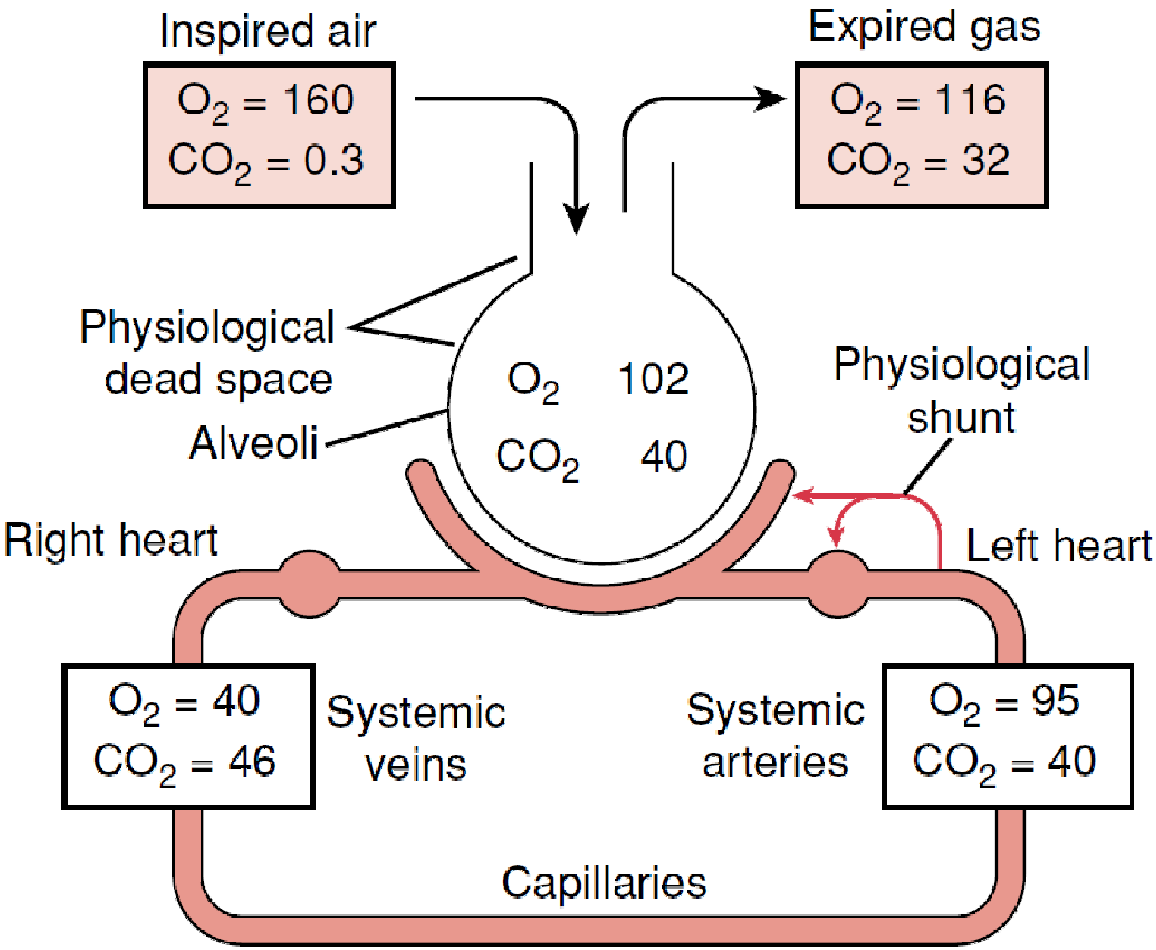
P_{O2} = 760 x 0,21 = ~160 mm Hg

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)

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



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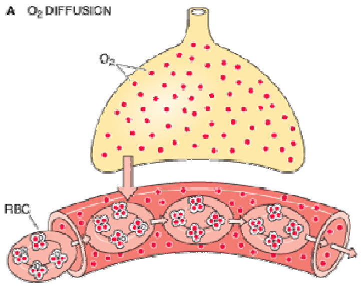
A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2



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)

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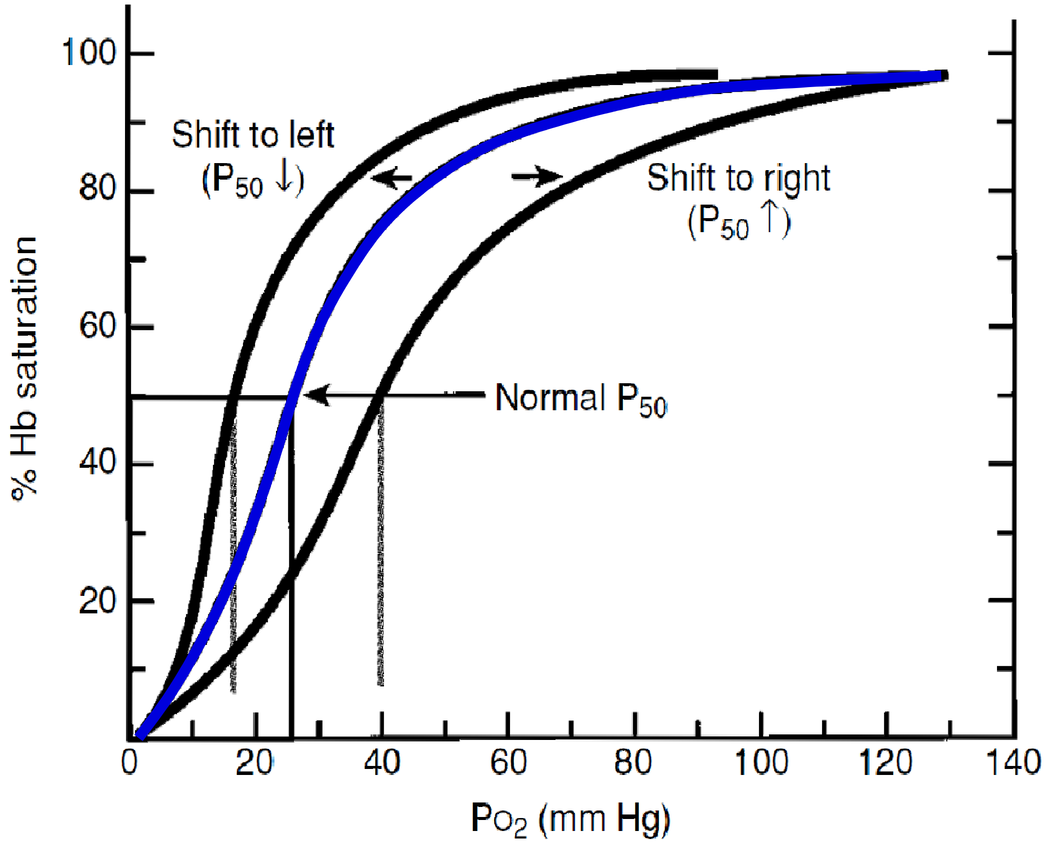
A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2



Dissociation curve of Hb is influenced by:

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

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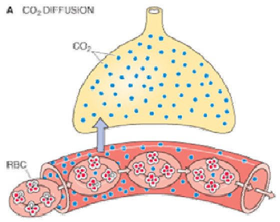
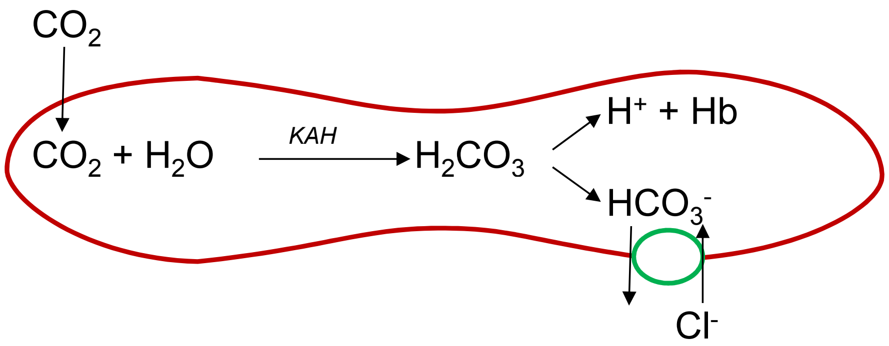
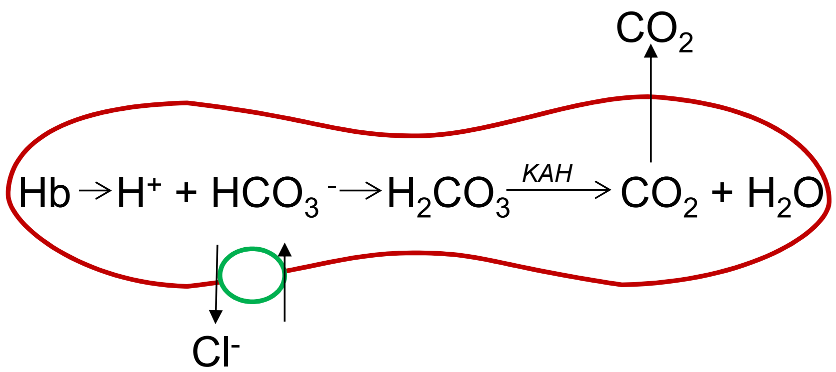
A48: Transport of O2. Oxygen - haemoglobin dissociation curve. Transport of CO2



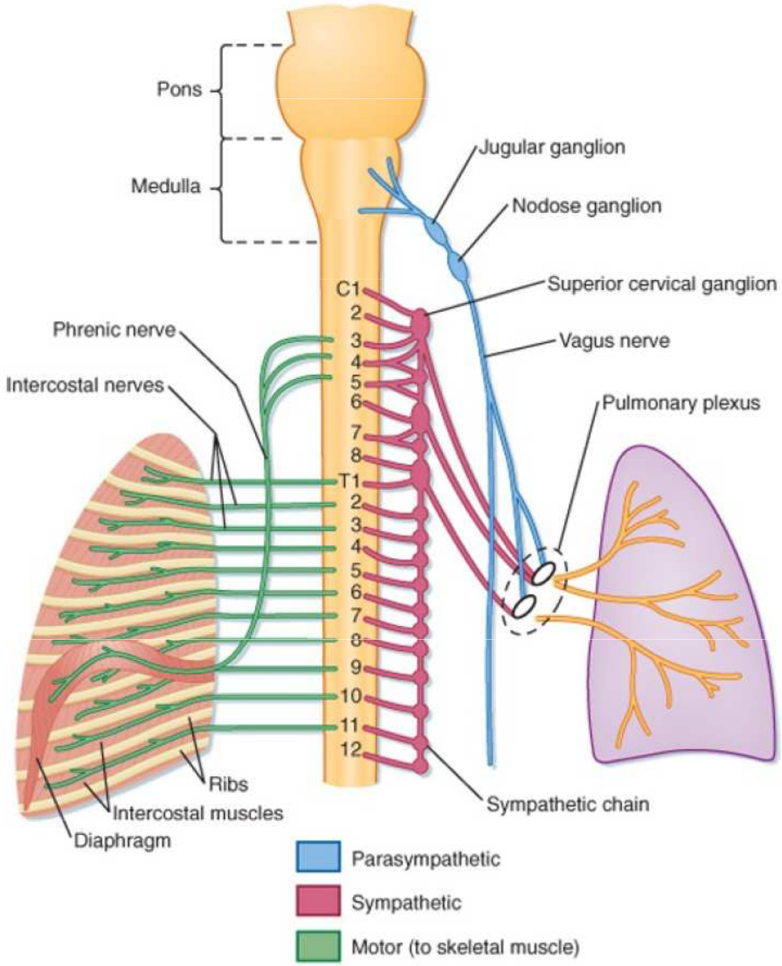
CO_2 is transported in next forms :

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

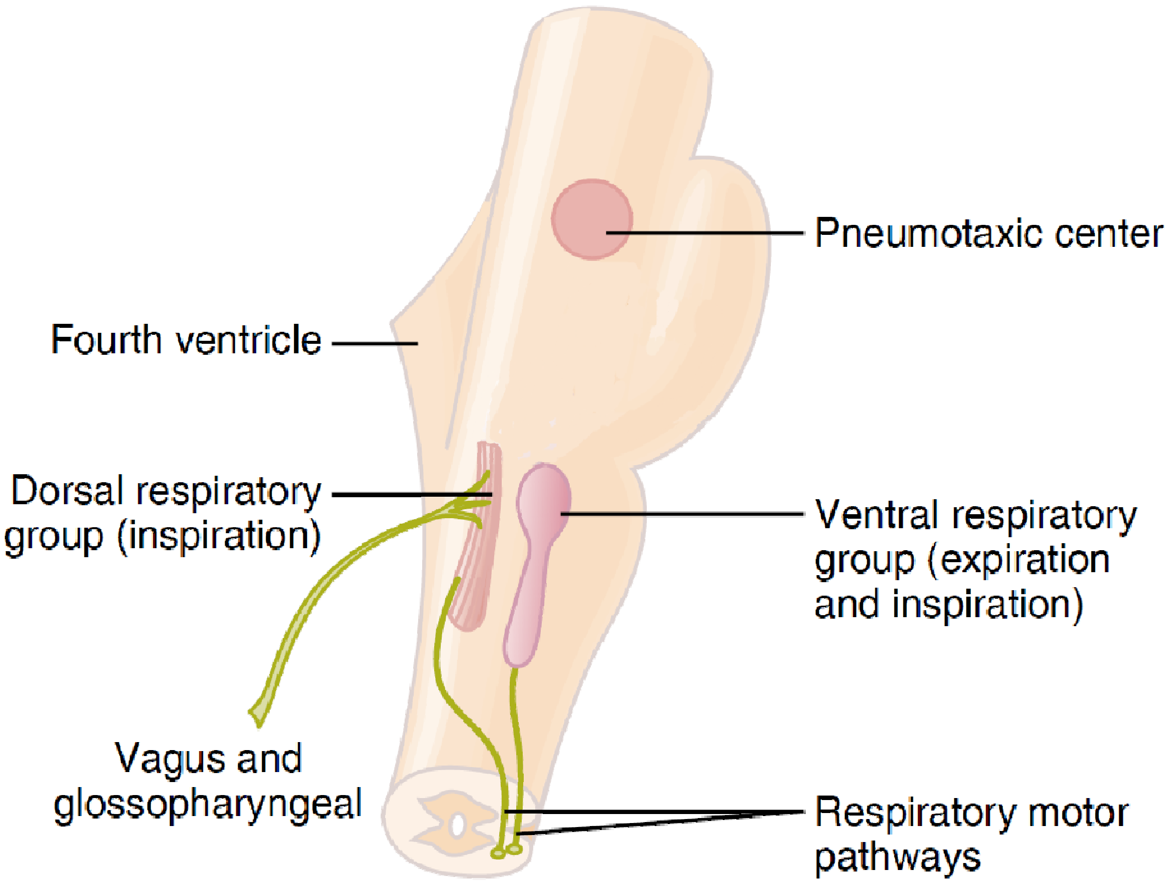




A49: Regulation of ventilation



A49: Regulation of ventilation



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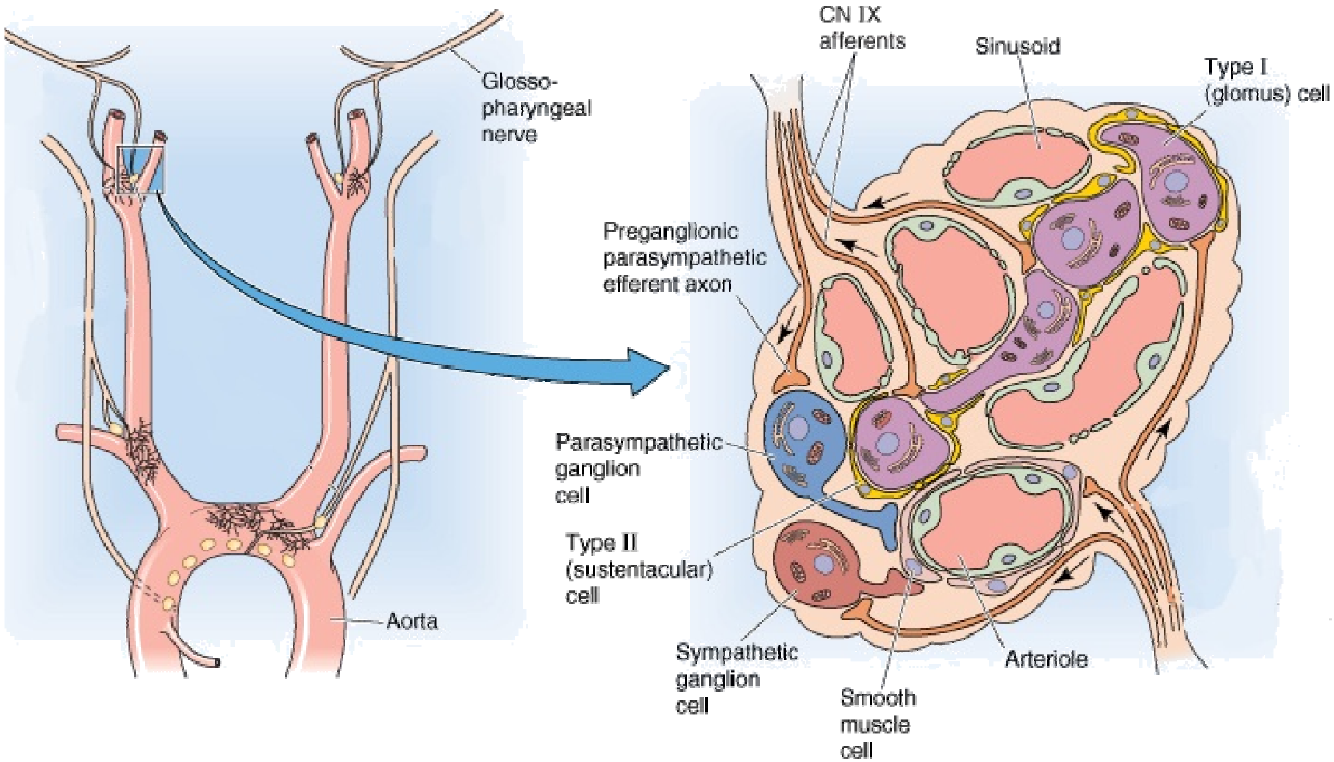
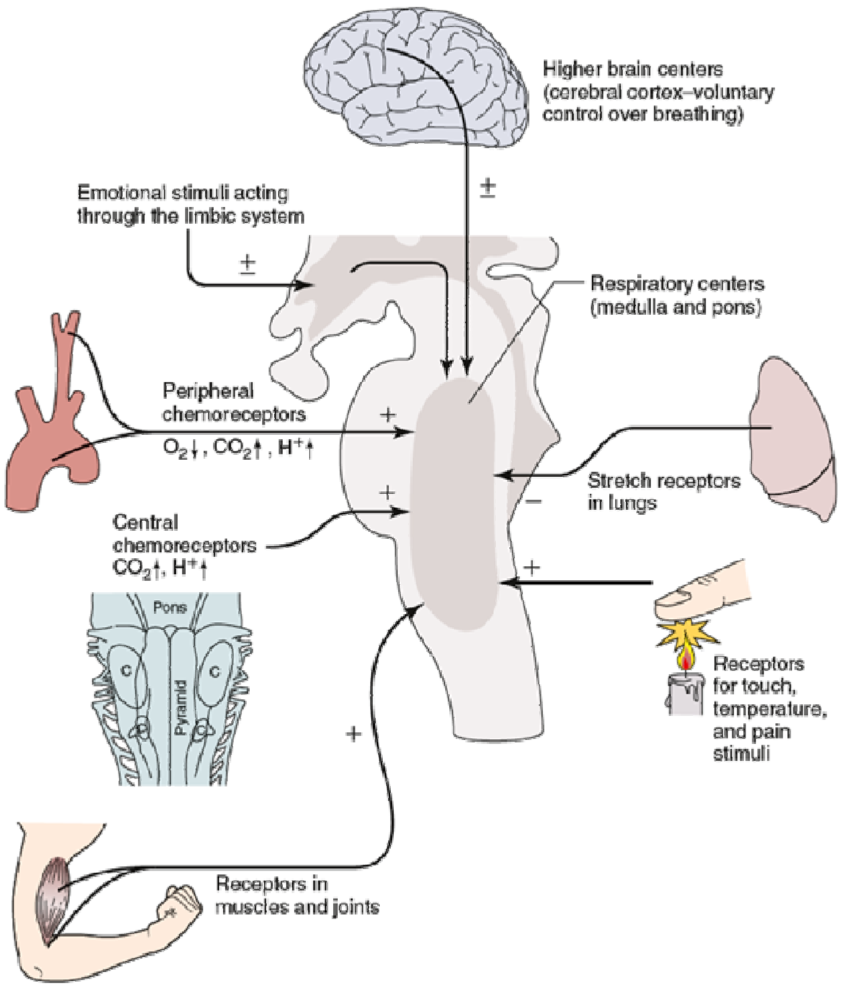
A49: Regulation of ventilation



A49: Regulation of ventilation



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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

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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.	Sneeze is defined as the involuntary expulsion of air containing irritants from nose.	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 cough:	*Causes of sneeze:*	*Causes of hiccup:*
– Irritants-smokes, fumes, dusts, etc. – Diseased conditions like COPD, tumors of thorax, etc.	– Irritation of nasal mucosa – Excess fluid in airway	– Eating too fast or too much – Strokes, brain tumors, damage to the vagus or phrenic nerve – Anxiety and stress
Pathway for cough reflex:	*Pathway for sneeze reflex:*	*Pathway for sneeze 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	– 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	– 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*

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