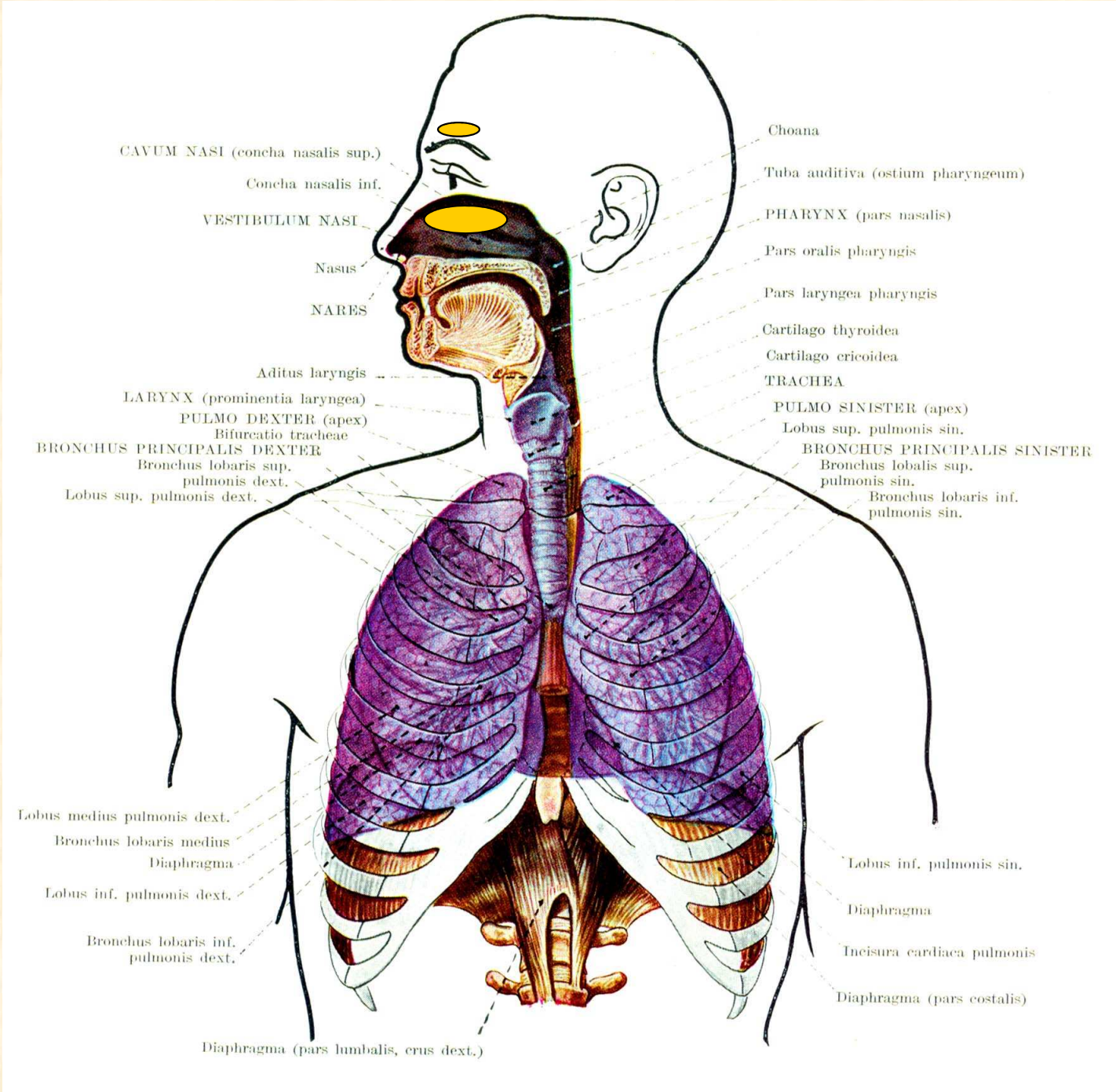
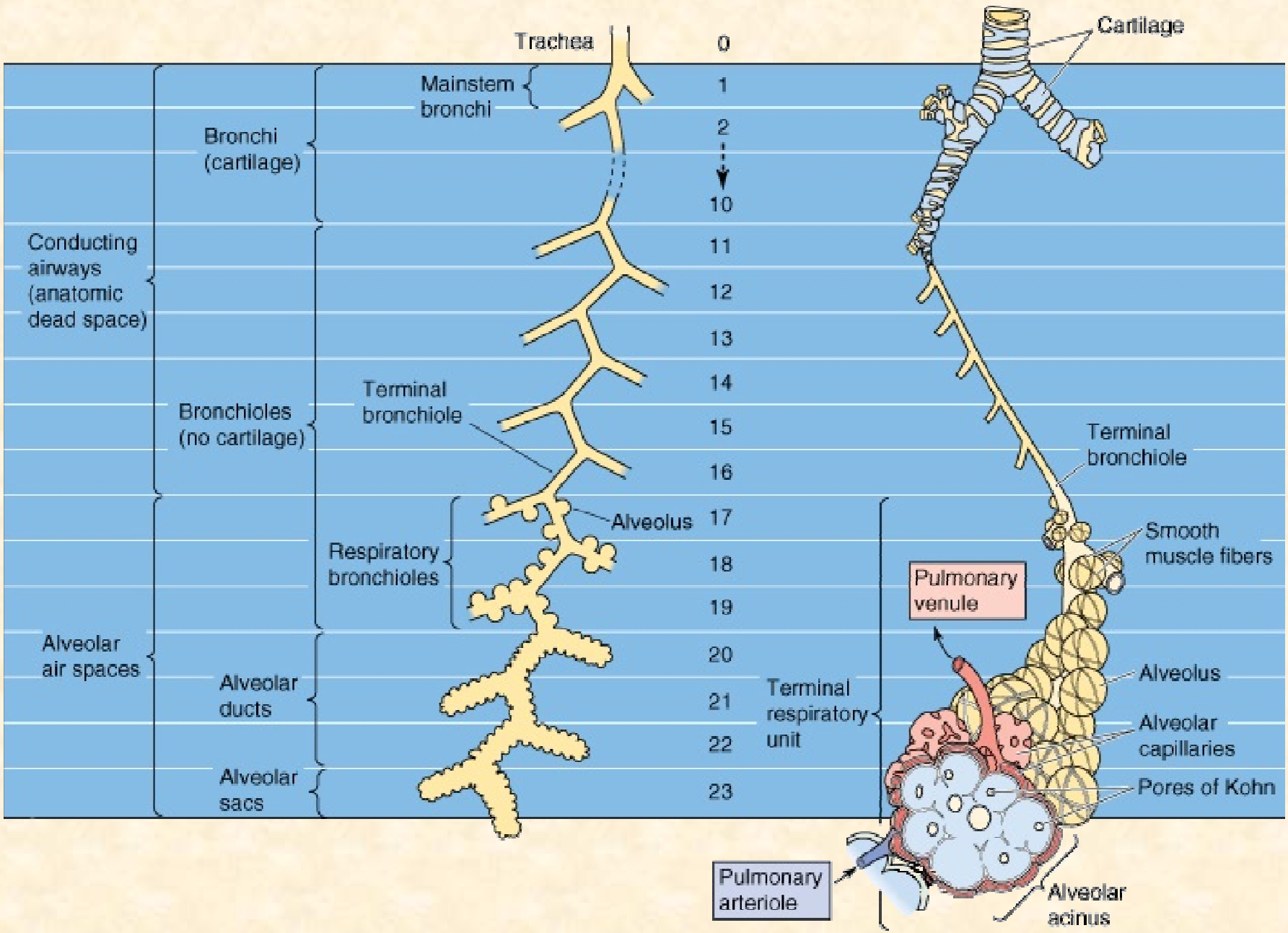
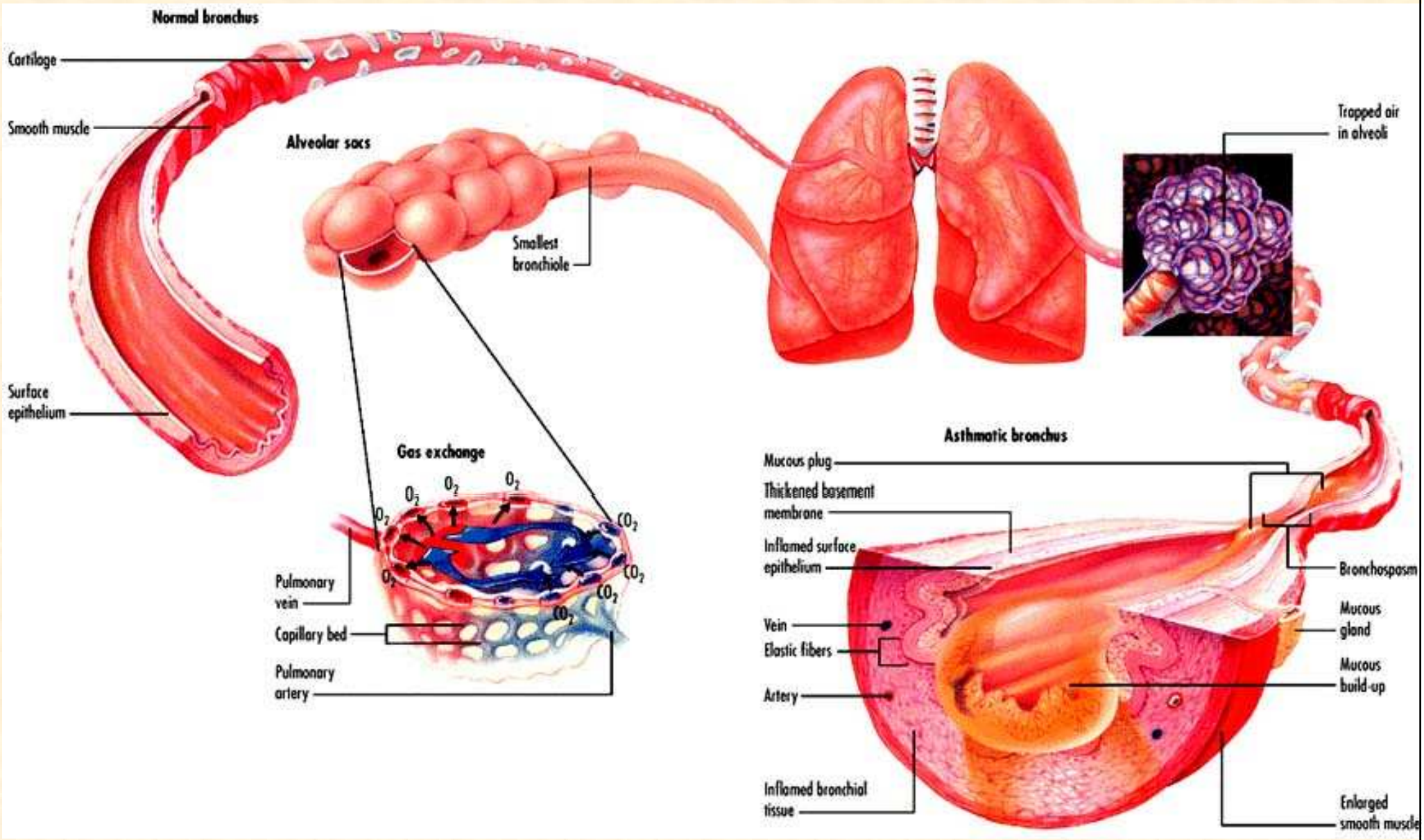
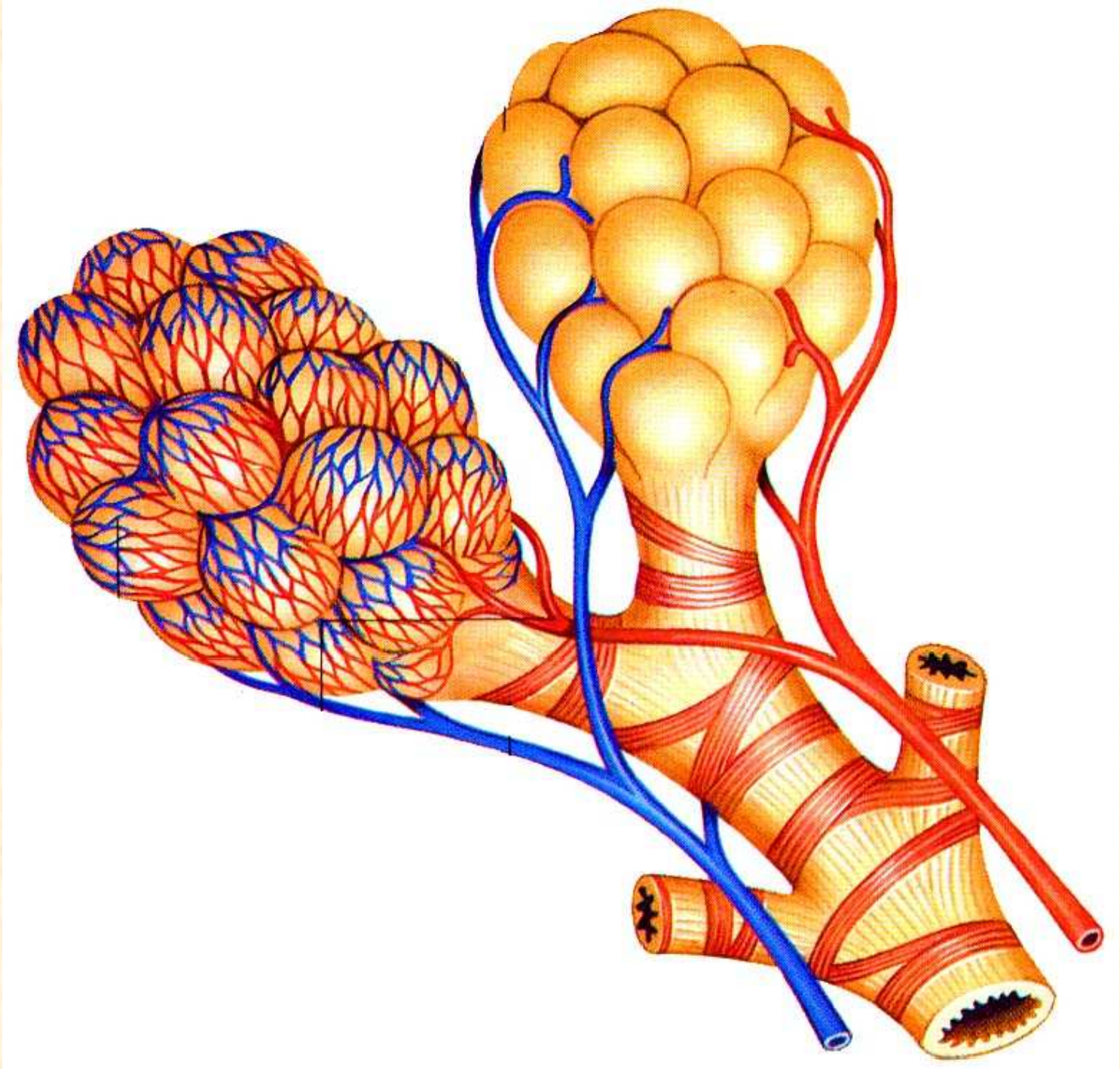
RESPIRATORY SYSTEM

RESPIRATORY FUNCTIONS
MECHANICS OF RESPIRATORY SYSTEM
GAS TRANSPORT


CAVUM NASI (concha nasalis sup.)
Concha nasalis inf.
VESTIBULUM NASI
Nasus
NARES
Aditus laryngis
LARYNX (prominentia laryngea)
PULMO DEXTER (apex)
Bifurcatio tracheae
BRONCHUS PRINCIPALIS DEXTER
Bronchus lobaris sup. pulmonis dext.
Lobus sup. pulmonis dext.
Lobus medius pulmonis dext.
Bronchus lobaris medius
Diaphragma
Lobus inf. pulmonis dext.
Bronchus lobaris inf. pulmonis dext.
Diaphragma (pars lumbalis, crus dext.)
Choana
Tuba auditiva (ostium pharyngeum)
PHARYNX (pars nasalis)
Pars oralis pharyngis
Pars laryngea pharyngis
Cartilago thyroidea
Cartilago cricoidea
TRACHEA
PULMO SINISTER (apex)
Lobus sup. pulmonis sin.
BRONCHUS PRINCIPALIS SINISTER
Bronchus lobalis sup. pulmonis sin.
Bronchus lobaris inf. pulmonis sin.
Lobus inf. pulmonis sin.
Diaphragma
Incisura cardiaca pulmonis
Diaphragma (pars costalis)


Trachea
0
Mainstem bronchi
1
Bronchi (cartilage)
2
10
Conducting airways (anatomic dead space)
11
12
13
Terminal bronchiole
14
Bronchioles (no cartilage)
15
16
Alveolus
17
Respiratory bronchioles
18
19
Alveolar air spaces
20
Alveolar ducts
21
22
Alveolar sacs
23
Cartilage
Terminal bronchiole
Smooth muscle fibers
Pulmonary venule
Terminal respiratory unit
Alveolus
Alveolar capillaries
Pores of Kohn
Pulmonary arteriole
Alveolar acinus

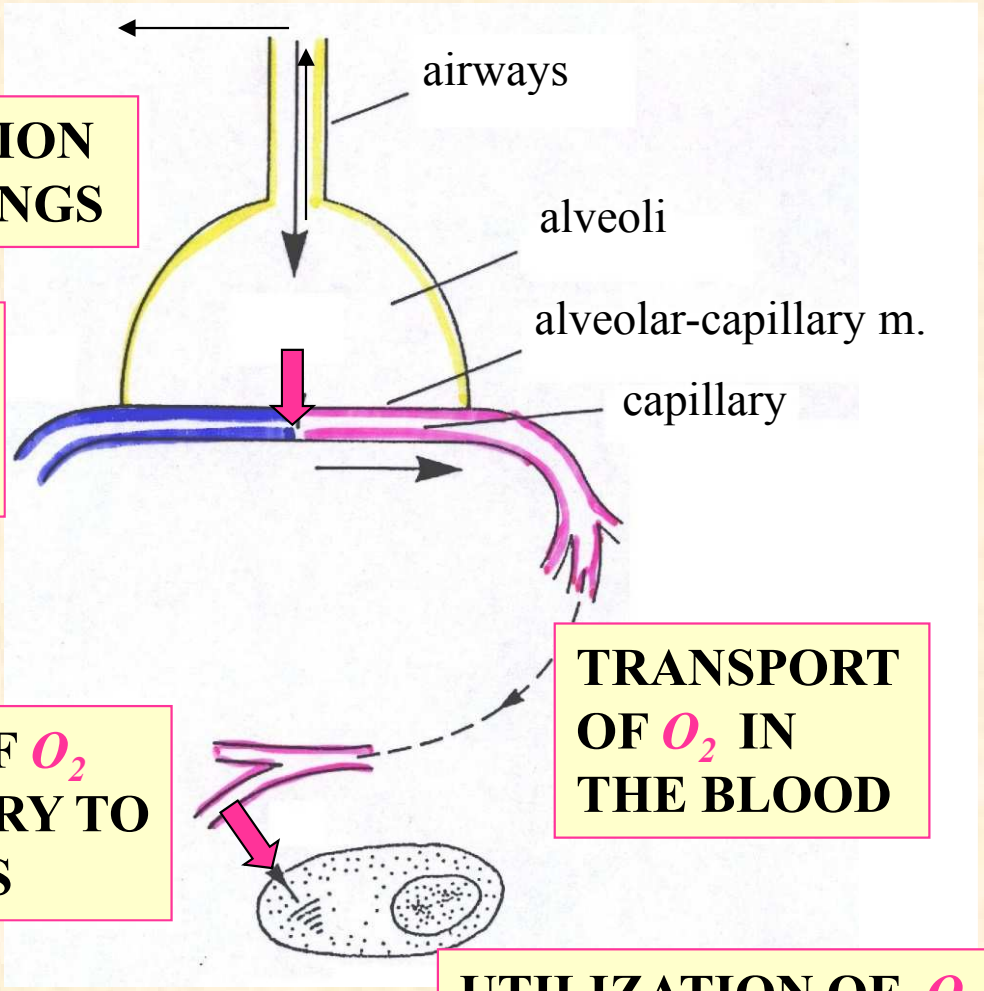

Normal bronchus
Cartilage
Smooth muscle
Surface epithelium
Alveolar sacs
Smallest bronchiole
Gas exchange
O_2
CO_2
Pulmonary vein
Capillary bed
Pulmonary artery
Trapped air in alveoli
Asthmatic bronchus
Mucous plug
Thickened basement membrane
Inflamed surface epithelium
Bronchospasm
Vein
Elastic fibers
Artery
Mucous gland
Mucous build-up
Inflamed bronchial tissue
Enlarged smooth muscle



STEPS IN THE DELIVERY OF O_2 TO THE CELLS

VENTILATION OF THE LUNGS

DIFFUSION OF O_2 ACROSS ALVEOLAR-CAPILLARY MEMBRANE



TRANSPORT OF O_2 IN THE BLOOD

DIFFUSION OF O_2 FROM CAPILLARY TO THE CELLS

UTILIZATION OF O_2 BY MITOCHONDRIA

AT REST

O_2 UPTAKE ~300 ml / min

CO_2 OUTPUT ~250 ml / min

INTERNAL RESPIRATION

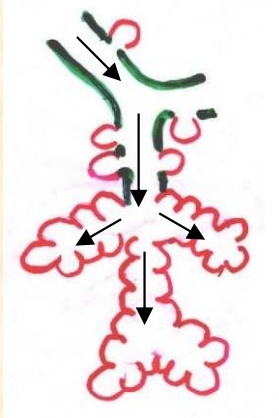
AIR PASSAGES

ANATOMICAL DEAD SPACE –CONDUCTING ZONE

- NASAL PASSAGES
- PHARYNX
- LARYNX
- TRACHEA
- BRONCHI
- BRONCHIOLES
- TERMINAL BRONCHIOLES

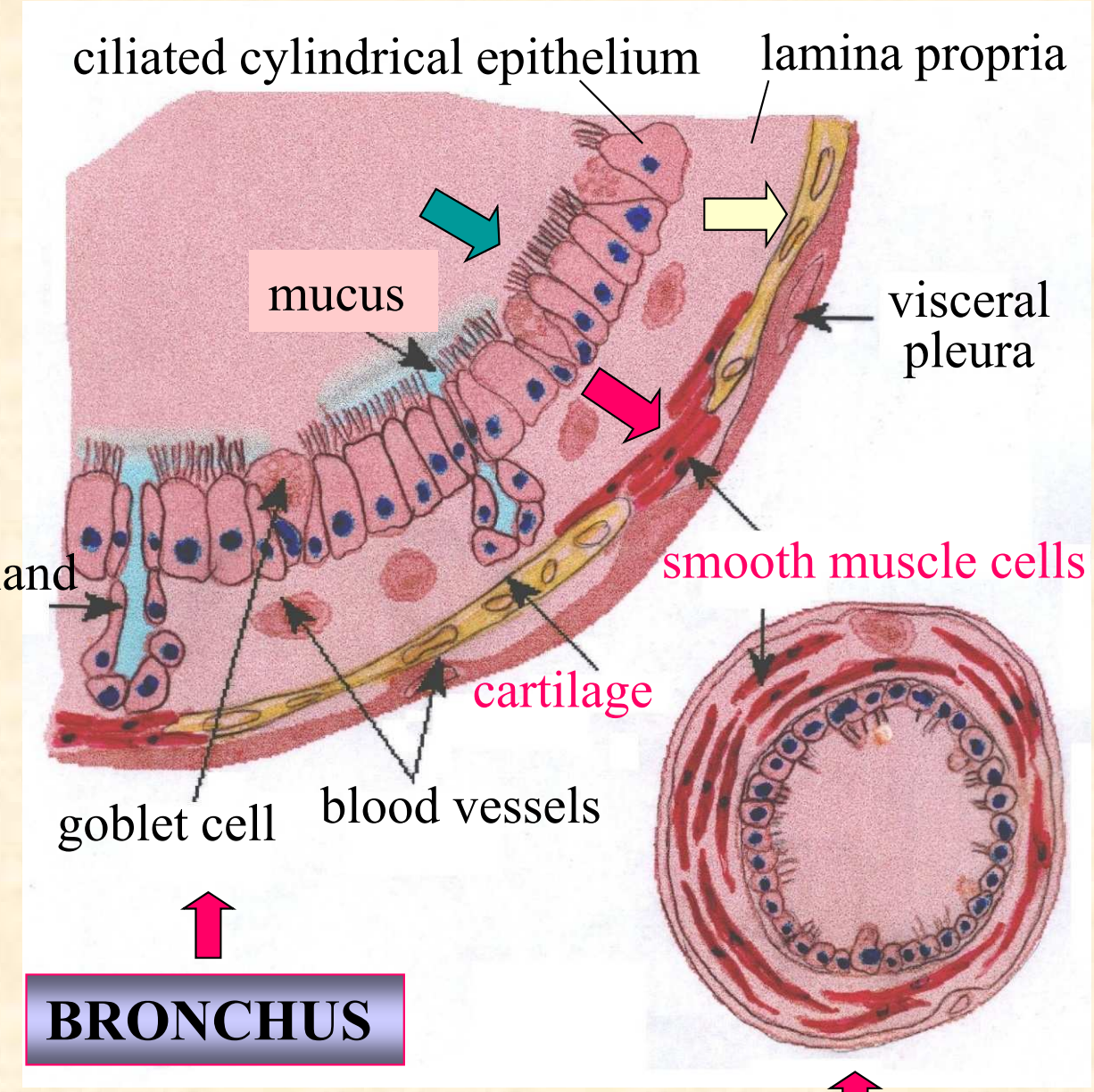
Other physiological functions:

- air is warmed, cleaned and takes up water vapour
- respiratory reflex responses to the irritants
- speech and singing (function of larynx)



RESPIRATORY ZONE
(GAS EXCHANGE)

Total alveolar area ~100 m^2



BRONCHUS

TERMINAL BRONCHIOLE

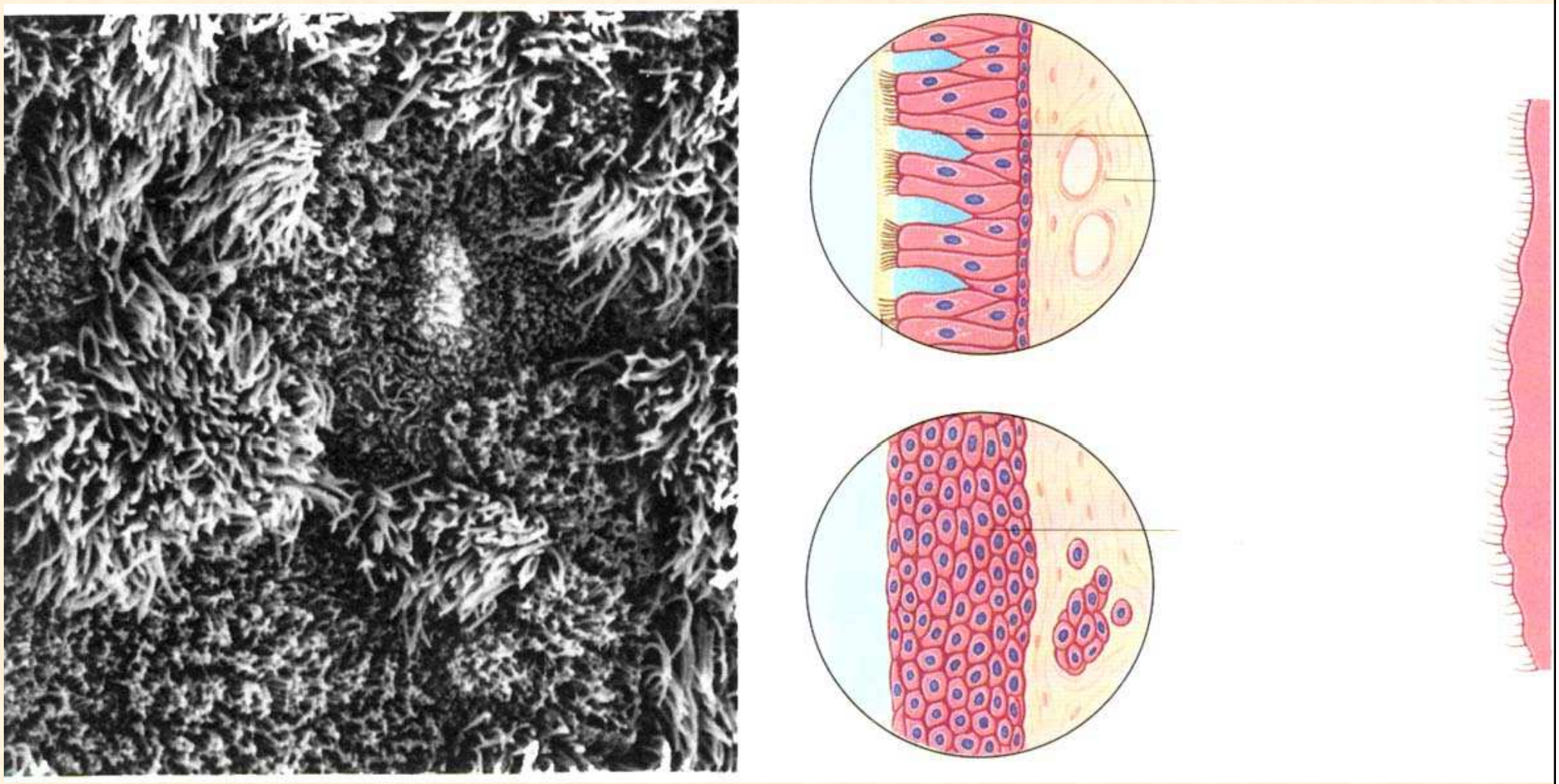
∅ < 1 mm

AUTONOMIC INNERVATION of smooth muscle cells

Stimulation via parasympathetic NS - n.vagus due to Muscarinic receptors: Acetylcholine activates bronchoconstriction

Stimulation via to sympathetic NS – due to catecholamins in circulation

β_2-adrenergic receptors: Noradrenaline activates bronchodilatation



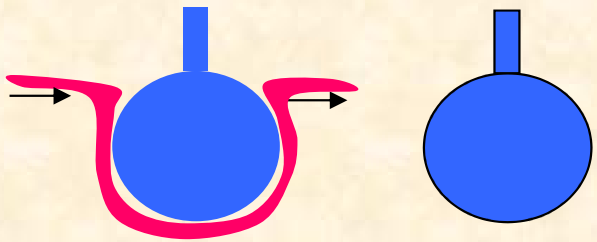
Cylindrical epithelium with cilia

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

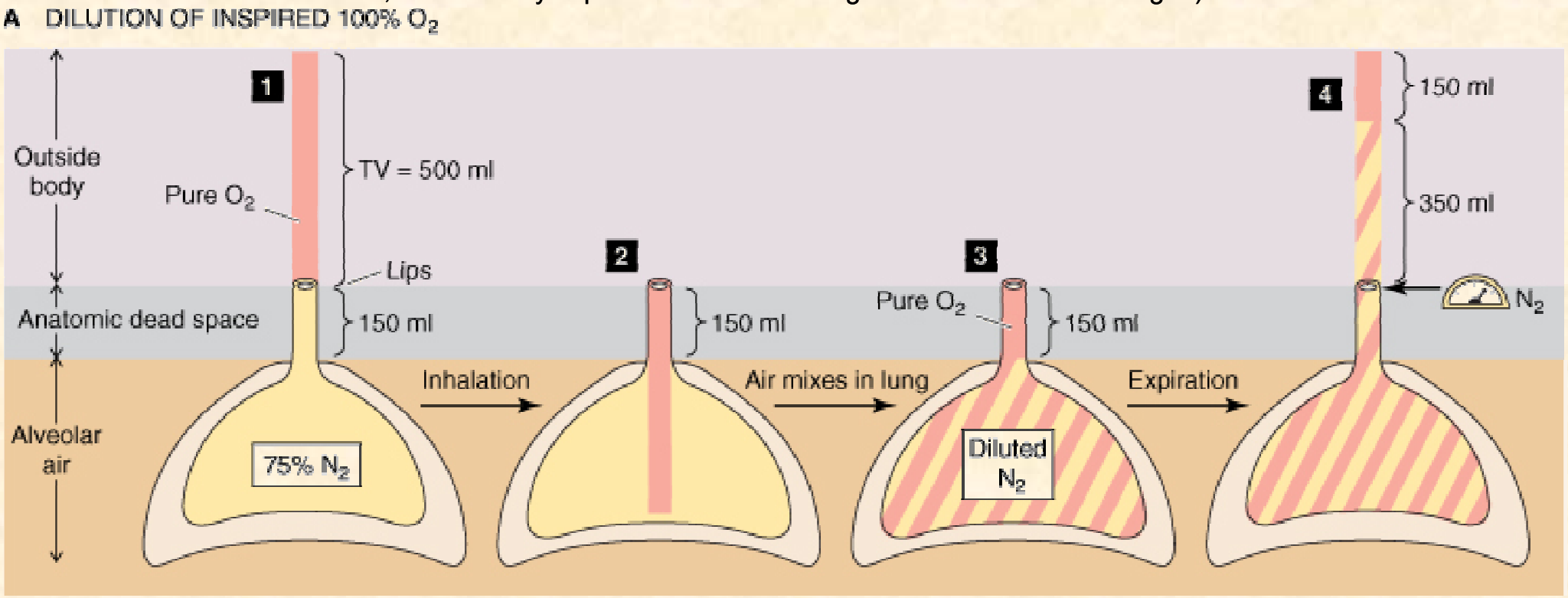
4.2 l/min

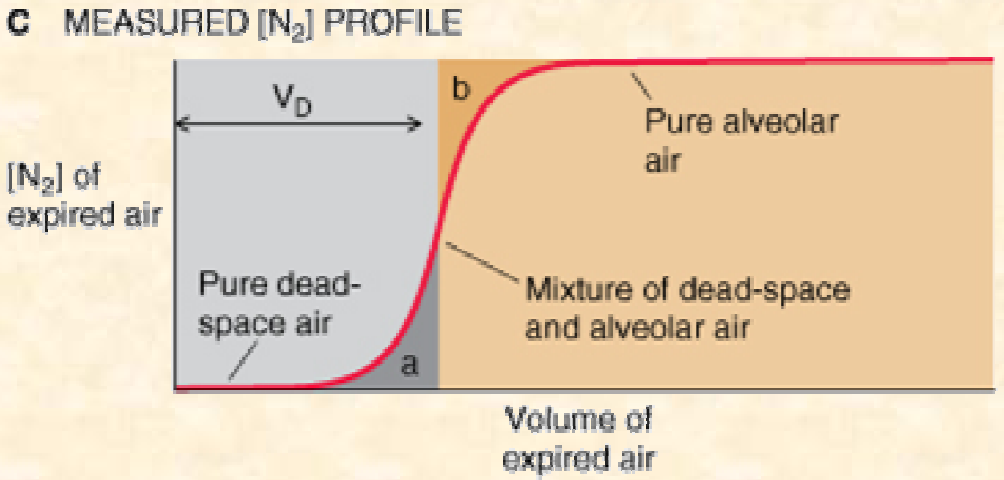
$\dot{V}_D = V_D \times f$

DEAD SPACE VENTILATION

1.8 l/min

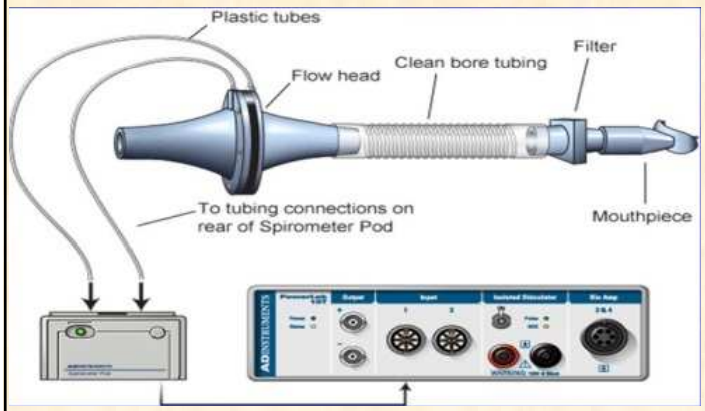
DEAD SPACE – nitrogen test (force inspiration of pure O2, follow slowly expiration with monitoring of concentration of nitrogen)

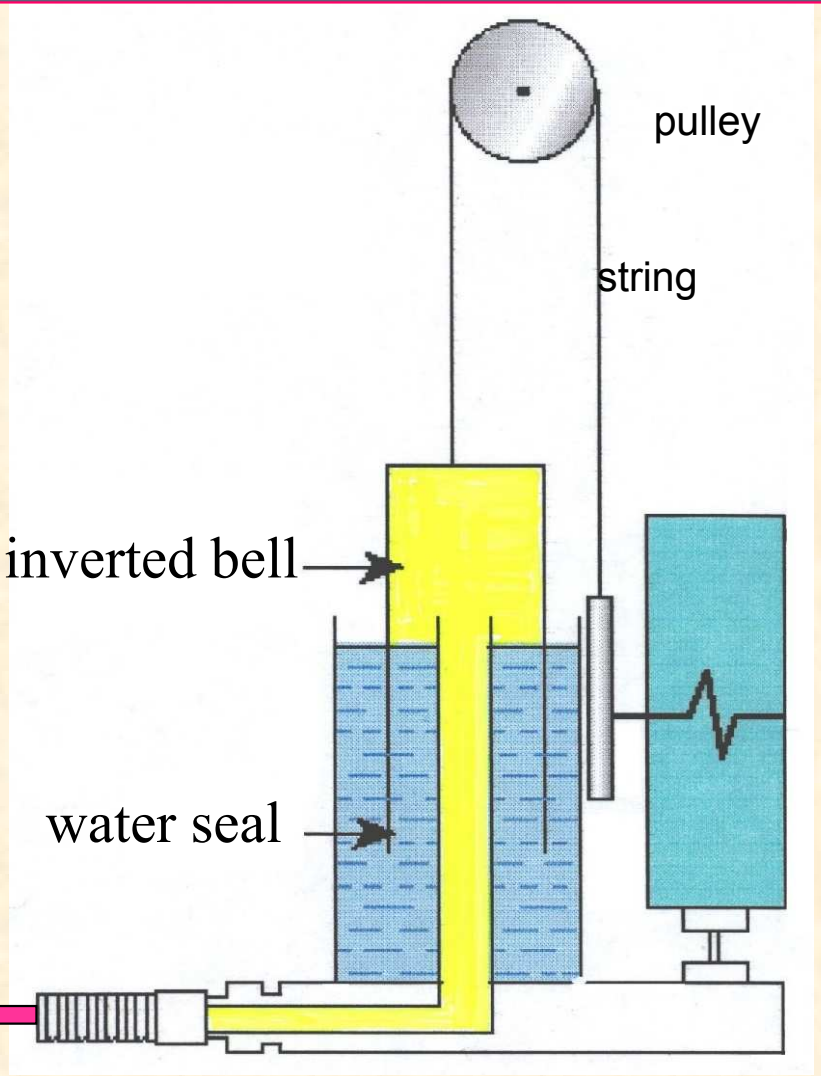




SPIROMETRY

(measurements of lung volumes, capacities, functional investigations, …)





inspiration

expiration

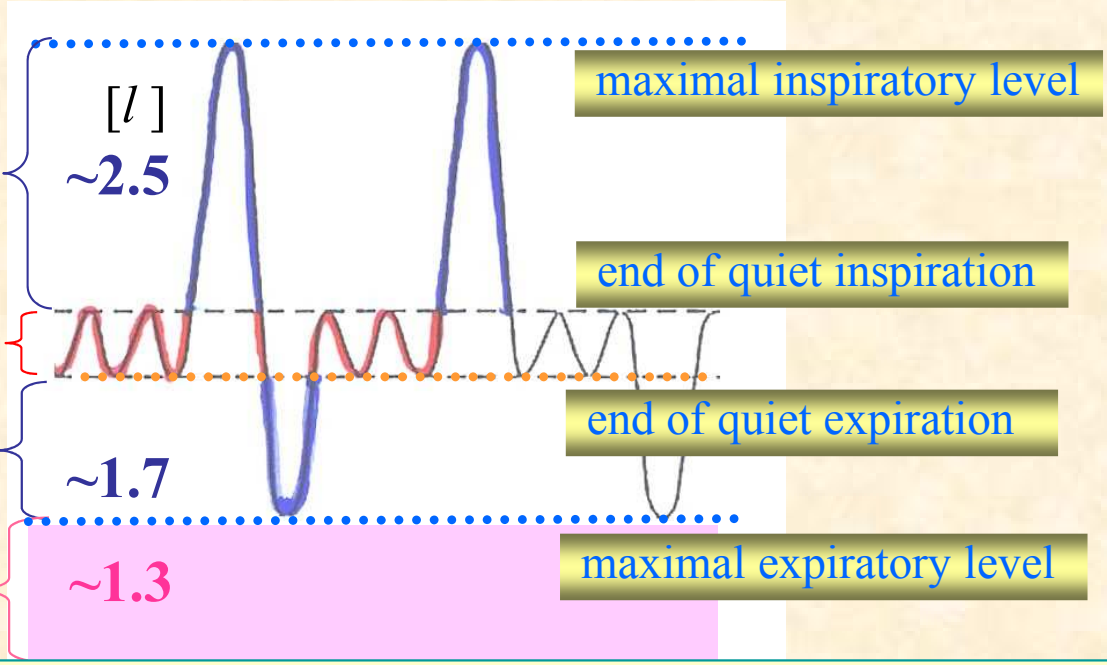
LUNG VOLUMES

INSPIRATORY RESERVE VOLUME *IRV*

TIDAL VOLUME V_T

EXPIRATORY RESERVE VOLUME *ERV*

RESIDUAL VOLUME *RV*

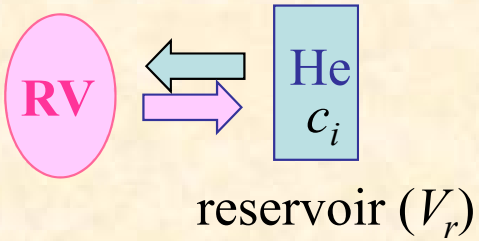


DILUTION METHOD *He*

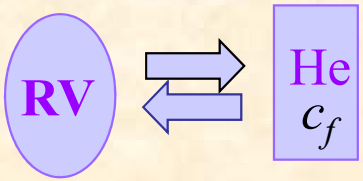
Principle of method: **1** Maximal expiration, **2** Repeated inspiration from and expiration into a reservoir (known **volume** V_r) with inert gas ***He*** (known concentration c_i)

⇒ Equilibration of the air in the residual volume and reservoir

3 Calculation of **residual volume *RV*** from the initial and final *He* concentrations in reservoir (c_i , c_f).

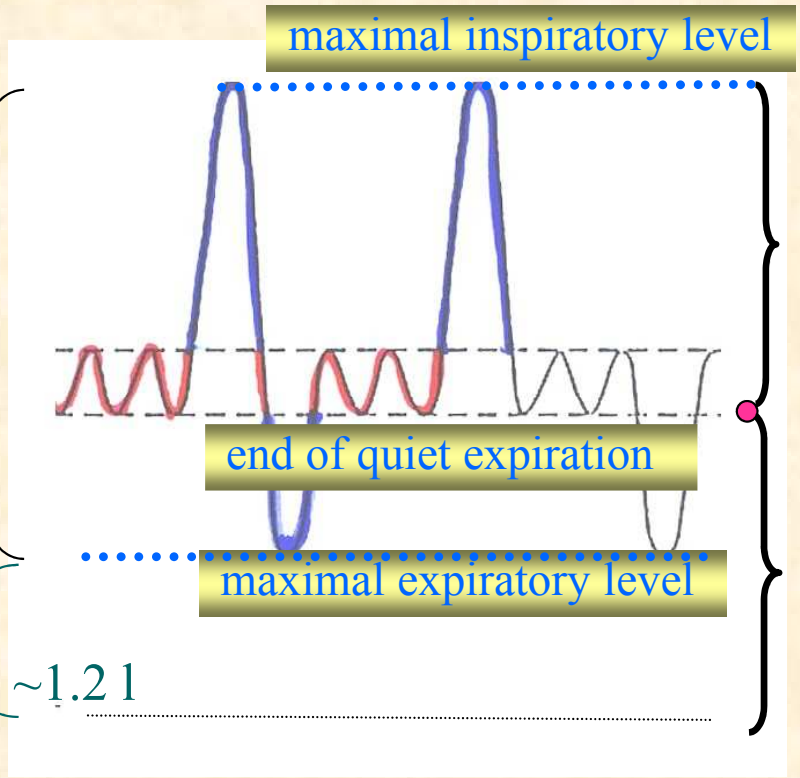


reservoir (V_r)



reservoir (V)

$$RV = V_r \frac{c_{i\,He} - c_{f\,He}}{c_{f\,He}}$$



TLC

VC

RV

INSPIRATORY CAPACITY

>3.0 l

FUNCTIONAL RESIDUAL CAPACITY

<3.0 l

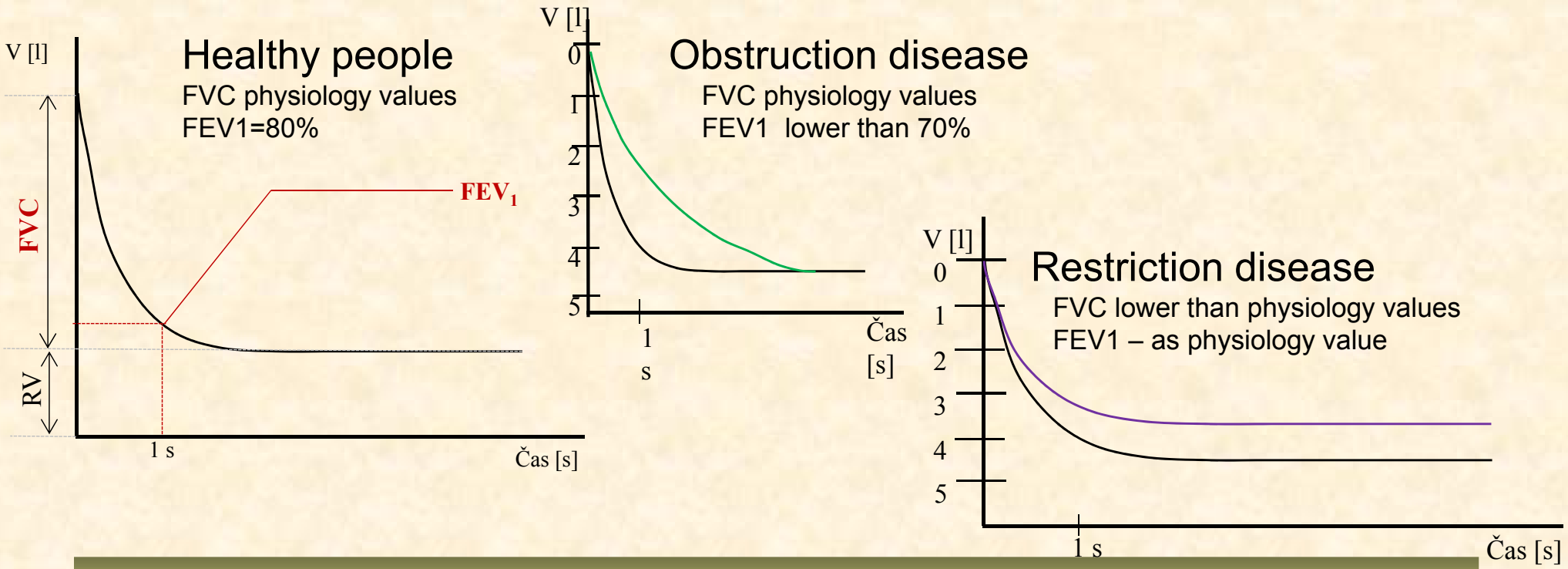
VC **VITAL CAPACITY = V_T + IRV + ERV** ~ 4.7 l

VC - the largest amount of air that can be expired after maximal inspiration

TLC **TOTAL LUNG CAPACITY = VC + RV** ~ 6.0 l

FUNCTIONAL INVESTIGATION OF THE LUNGS

- **TIMED VITAL CAPACITY (*FEV_1* - forced expiratory volume per 1 s)**

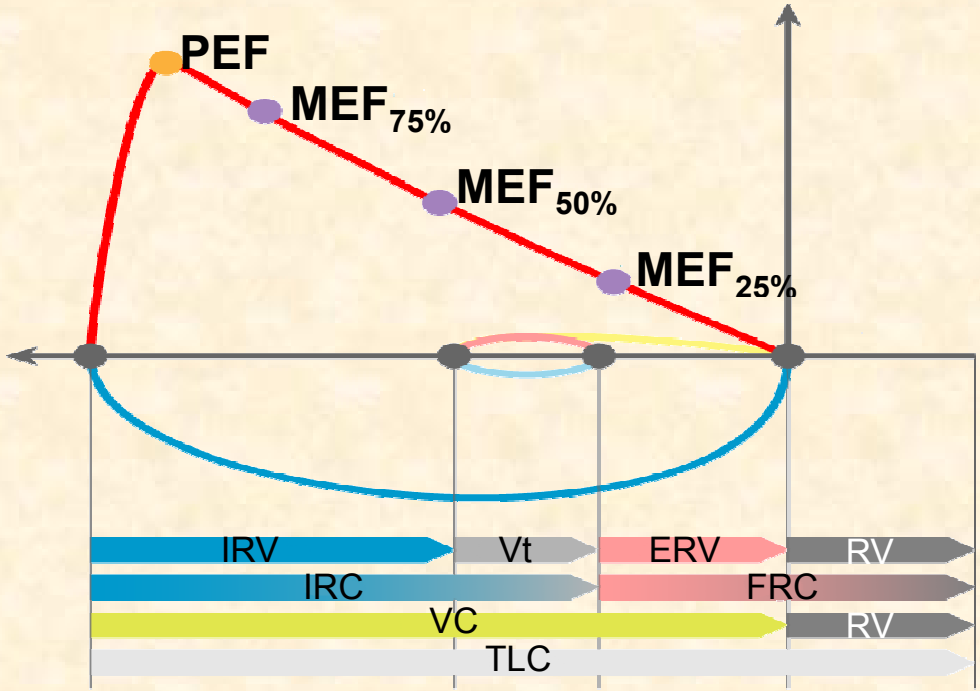


- **PULMONARY MINUTE VENTILATION *RMV* (respiratory minute volume) at rest** (0.5 l x 12 breathes/min = 6 l/min)
- **MAXIMAL VOLUNTARY VENTILATION (*MVV*)** (125-170 l/min)
- **PEAK EXPIRATORY FLOW RATE (*PEFR*)** (~10 l/s)

Flow – volume curve

Propeller spirometer

- **PEF** – peak expiratory flow
- **MEF** – maximální maximal expiratory flow on the differential levels of FVC - 75 %, 50 % a 25 % FVC



PNEUMOGRAPHY

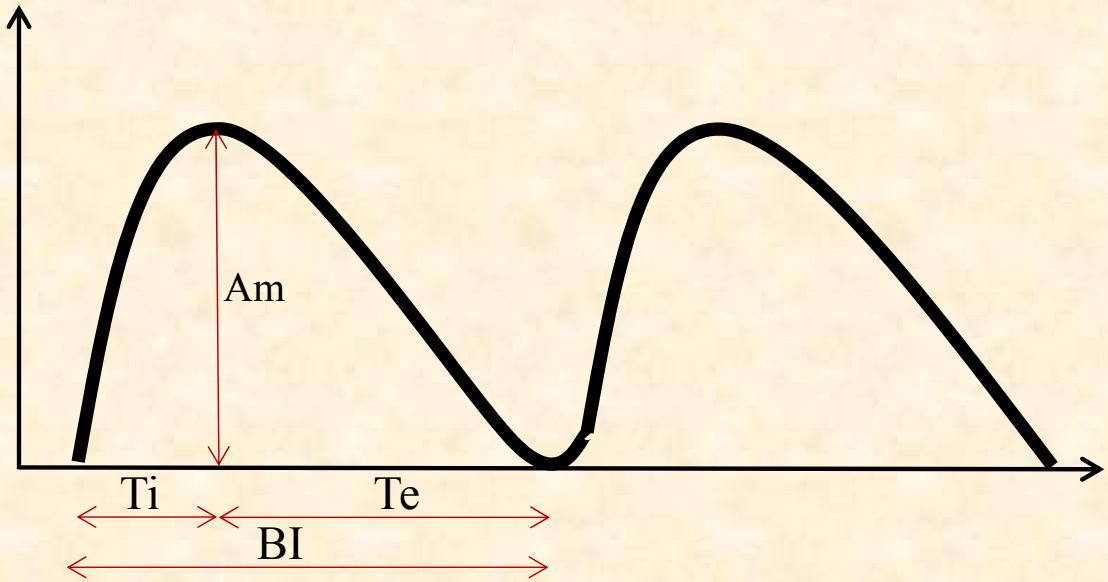
Principle

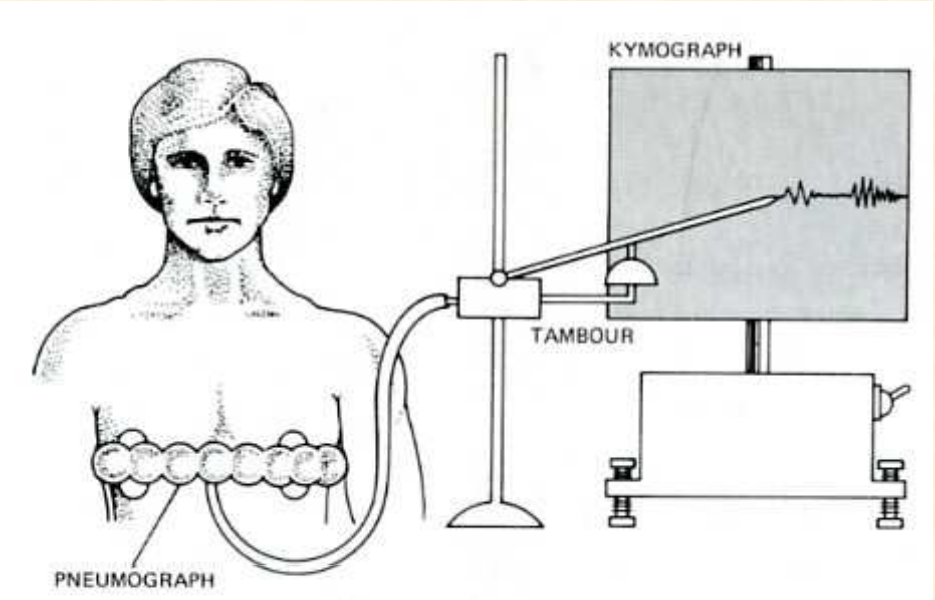
Pneumography – measurement of respiratory movements (via chest or abdomen)

- respiratory belt (piesoelectrical principle – is the ability of crystal to generate of electrical voltage during its deformation)

Record:

- Resting breathing
- Breathing after mild or intensive exercise
- Evaluation of record –Ti, Te, BI a Am

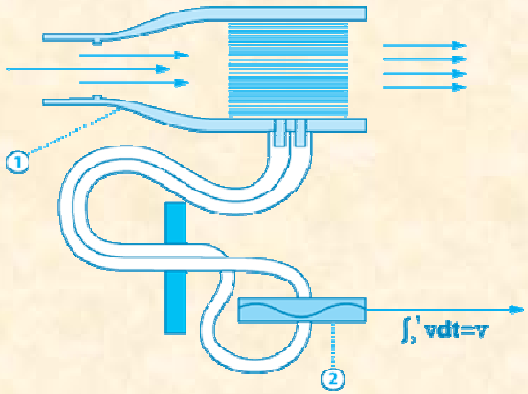


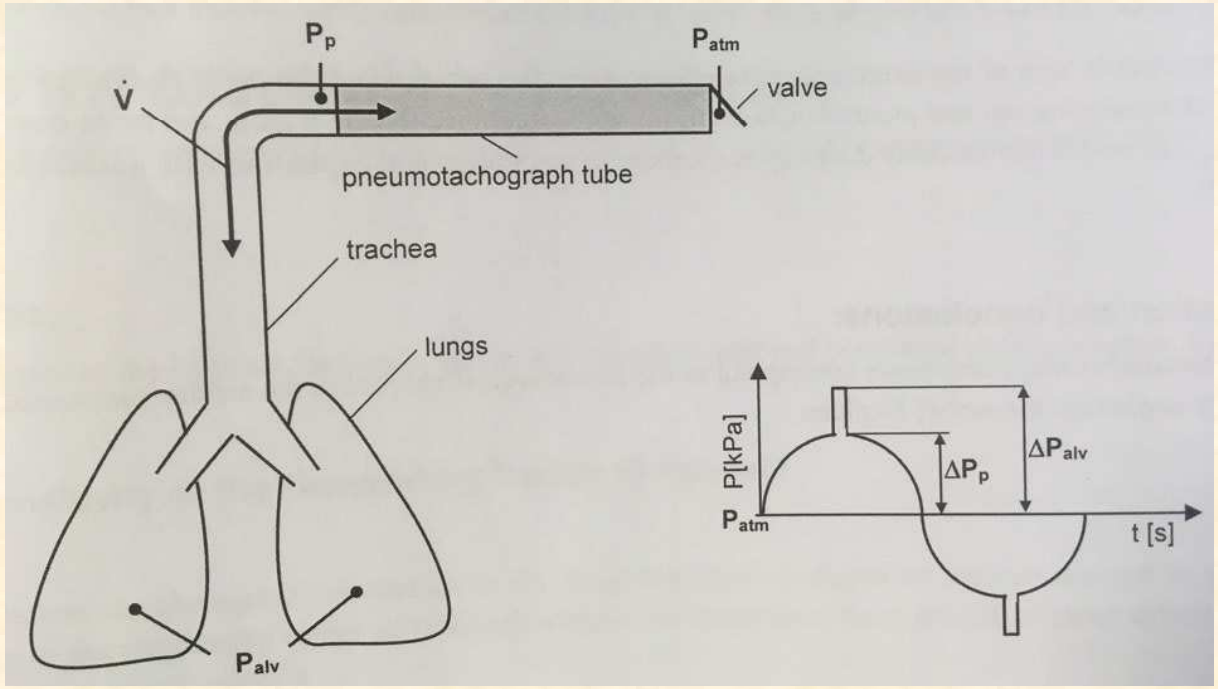


PNEUMOTACHOGRAPHY

Principle

Pneumotachograph - the device consists of tubes of the same diameter arranged in parallel. One of the tubes has branches with tubes near both its ends (oral and external). These are connected to a pressure sensor that allows you **to measure the differences in air pressure at the beginning and end of the pneumotachograph in proportion to the speed of the inhaled or exhaled air.**





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

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

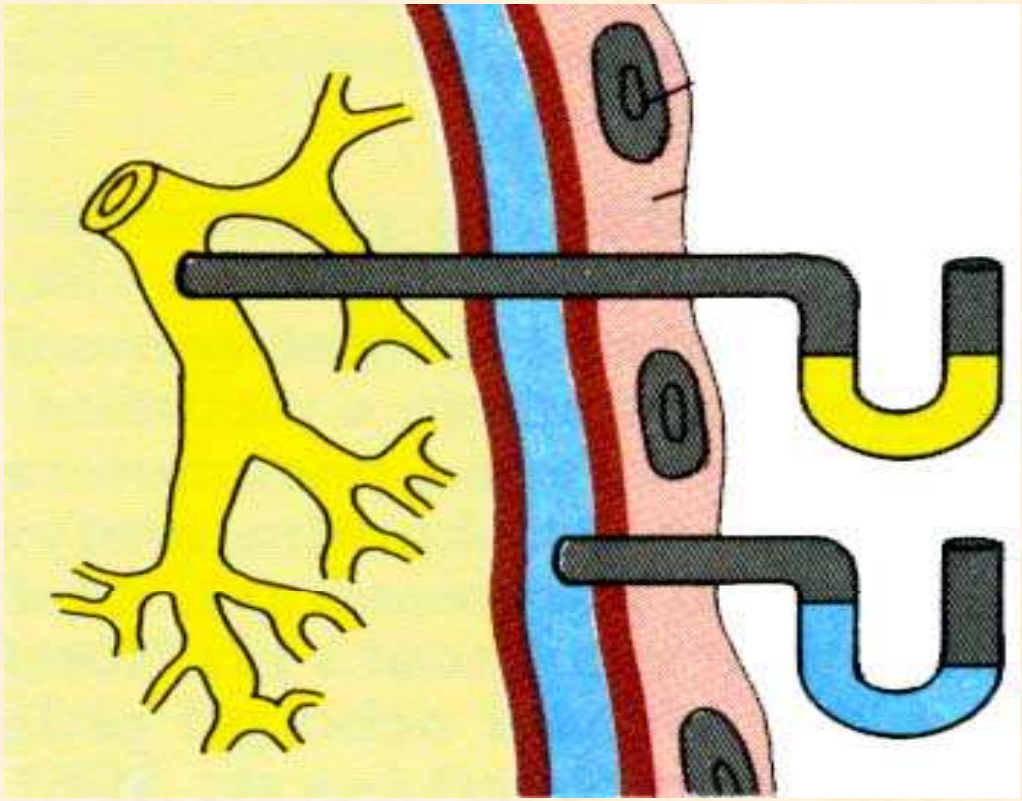
$$\frac{P_p - P_{atm}}{R_p} = \dot{V} = \frac{P_{alv} - P_p}{R_d}$$

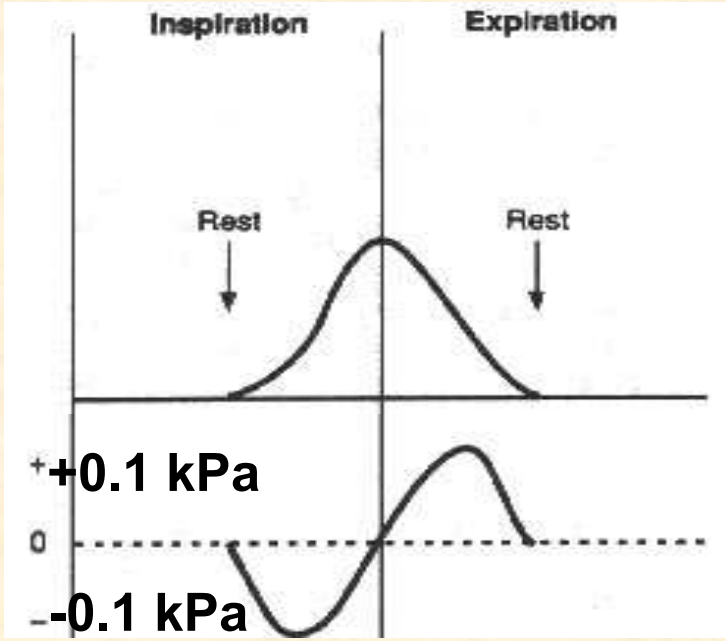
$$R_d = R_p \cdot \left(\frac{\Delta P_{alv}}{\Delta P_p} - 1 \right)$$

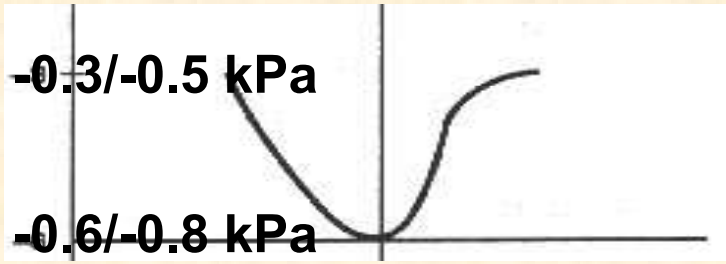
- Mechanics of breathing

PLEURA

pulmonalis parietalis







FORCES PARTICIPATING IN RESPIRATION

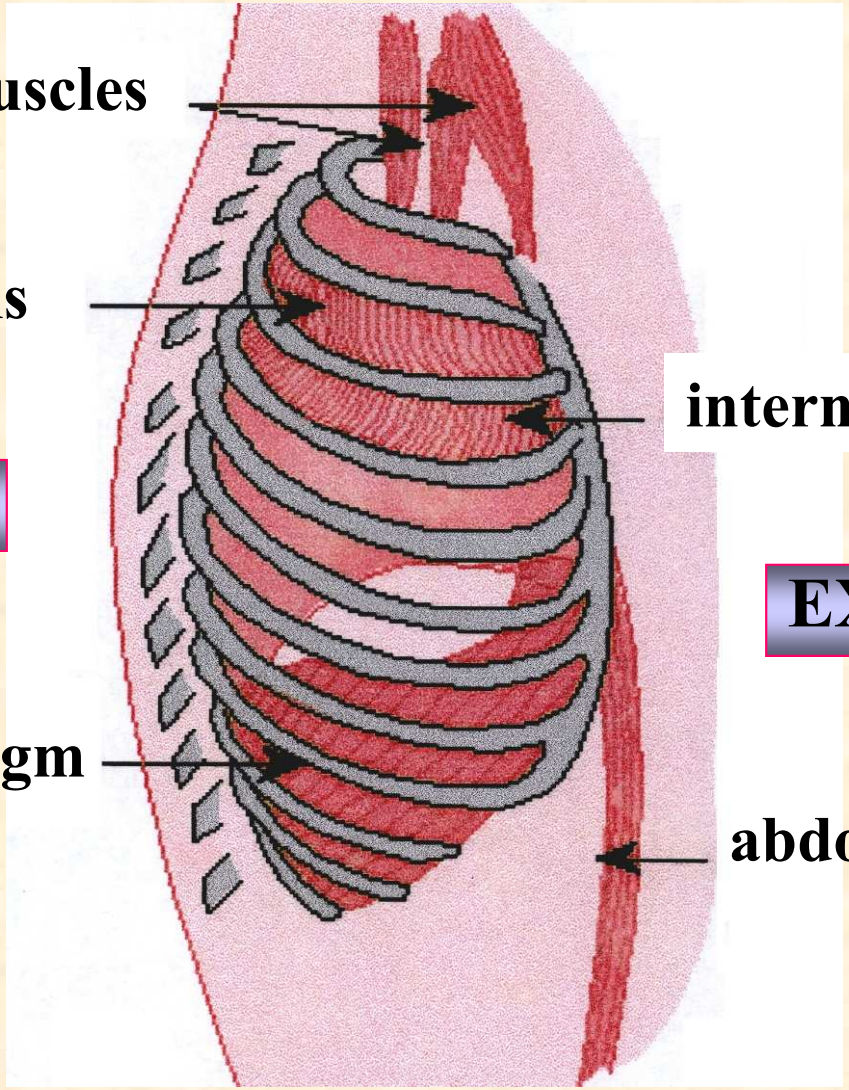
- **ACTIVE FORCES** performed by respiratory muscles
- **PASSIVE FORCES represented by:**
  - **lungs elasticity**
  - **chest elasticity**

QUIET RESPIRATION

INSPIRATION - active forces of inspiratory muscles prevail

EXPIRATION - only passive (elastic) forces are in action

RESPIRATORY MUSCLES



INSPIRATORY muscles

QUIET breathing

- ***diaphragm*** (> 80 %)
- ***external*** **intercostals** (< 20 %)

FORCED breathing

in addition

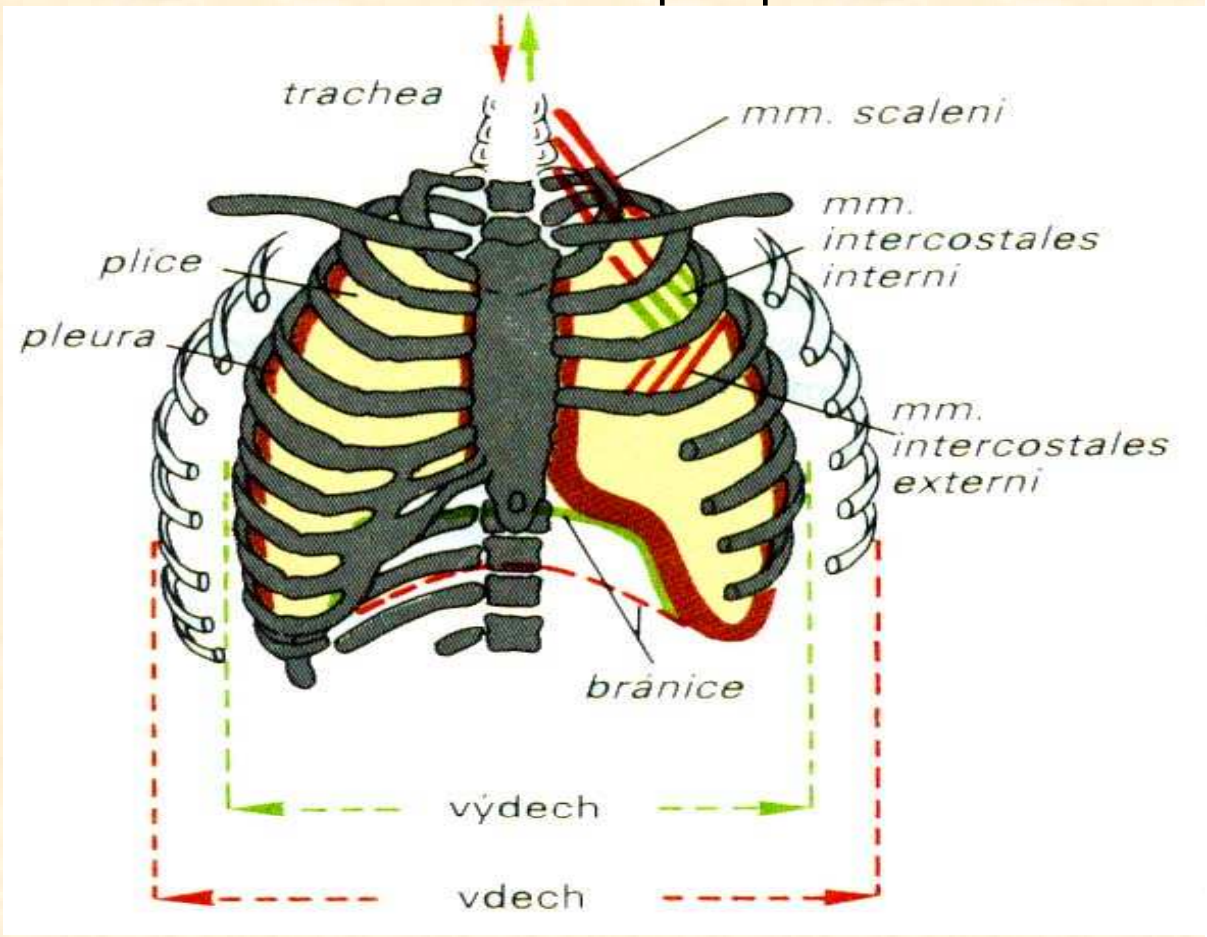
- ***accessory*** **inspiratory muscles** (mm. scalene)

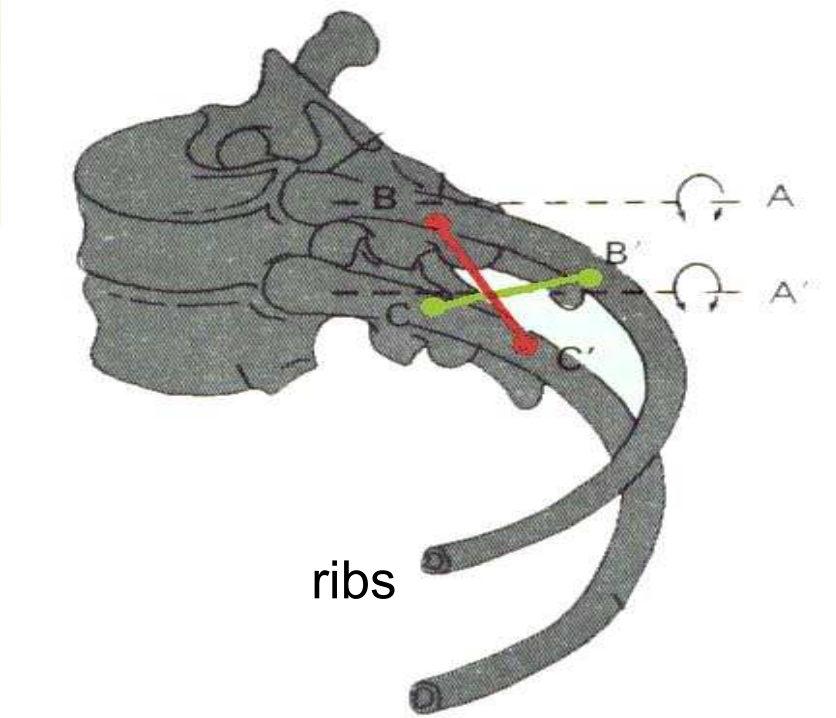
EXPIRATORY muscles

Only at FORCED breathing

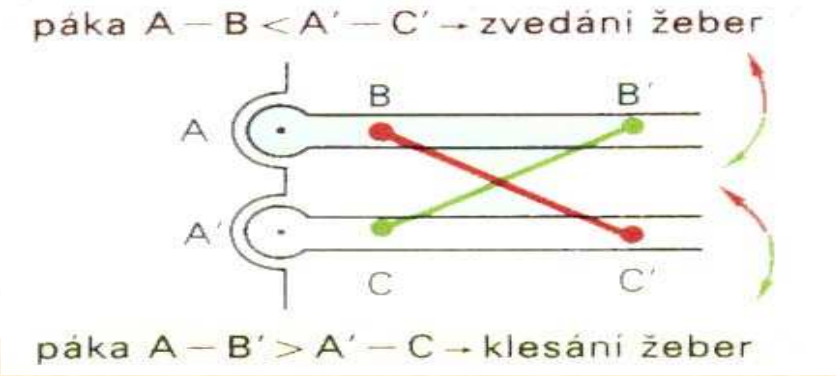
- ***internal*** **intercostals**
- **muscles of the anterior *abdominal* wall**
  (abdominal recti, …)

Bucket-handle and water-pump handle effects



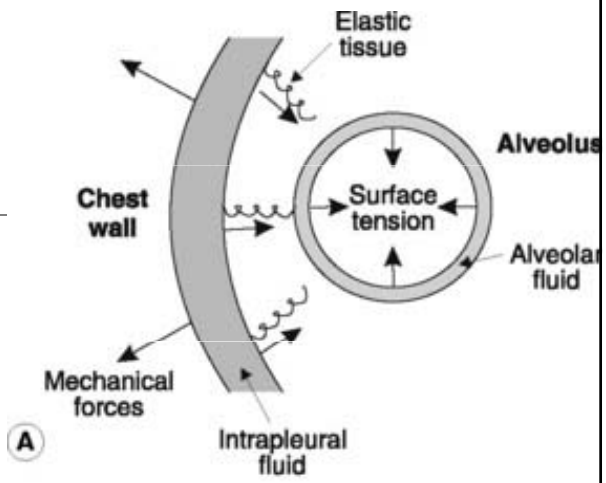


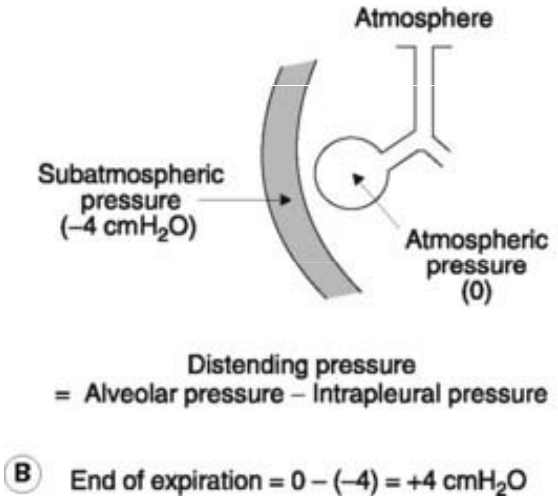
ribs



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)





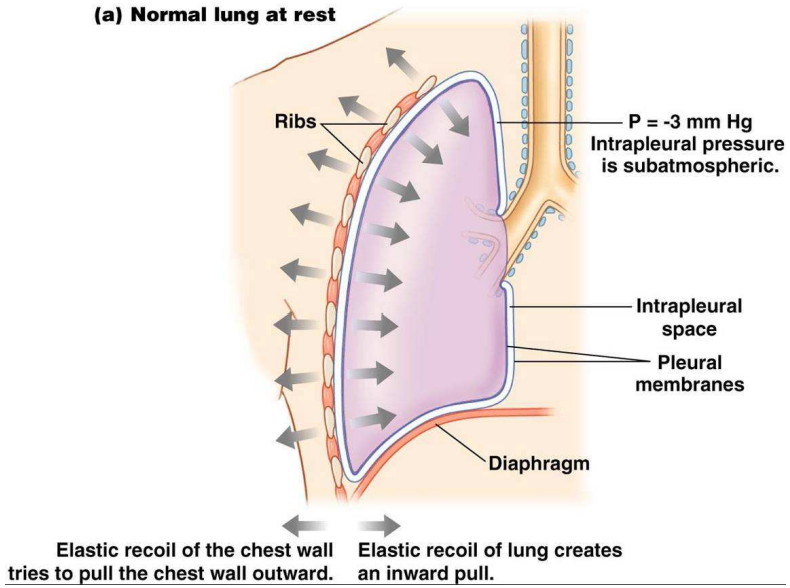
Lung recoil and chest wall recoil

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

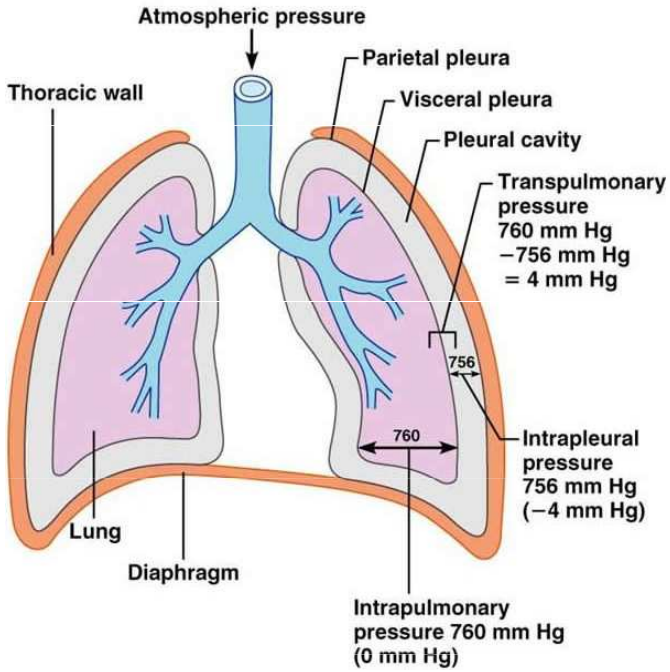
- Outward force of the chest wall
- FRC represents the point where this outward recoil of the chest wall is counterbalanced by the inward recoil of the lung.



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.



COMPOSITION OF DRY ATMOSPHERIC AIR

O_2	20.98 %	F_{O2}	$\cong 0.21$
N_2	78.06 %	F_{N2}	$\cong 0.78$
CO_2	0.04 %	F_{CO2}	$= 0.0004$

Other constituents

BAROMETRIC (ATMOSPHERIC) PRESSURE AT SEA LEVEL

1 atmosphere = 760 mm Hg

PARTIAL PRESSURES OF GASSES IN DRY AIR AT SEA LEVEL

P_{O2} = 760 x 0.21 = ~160 mm Hg

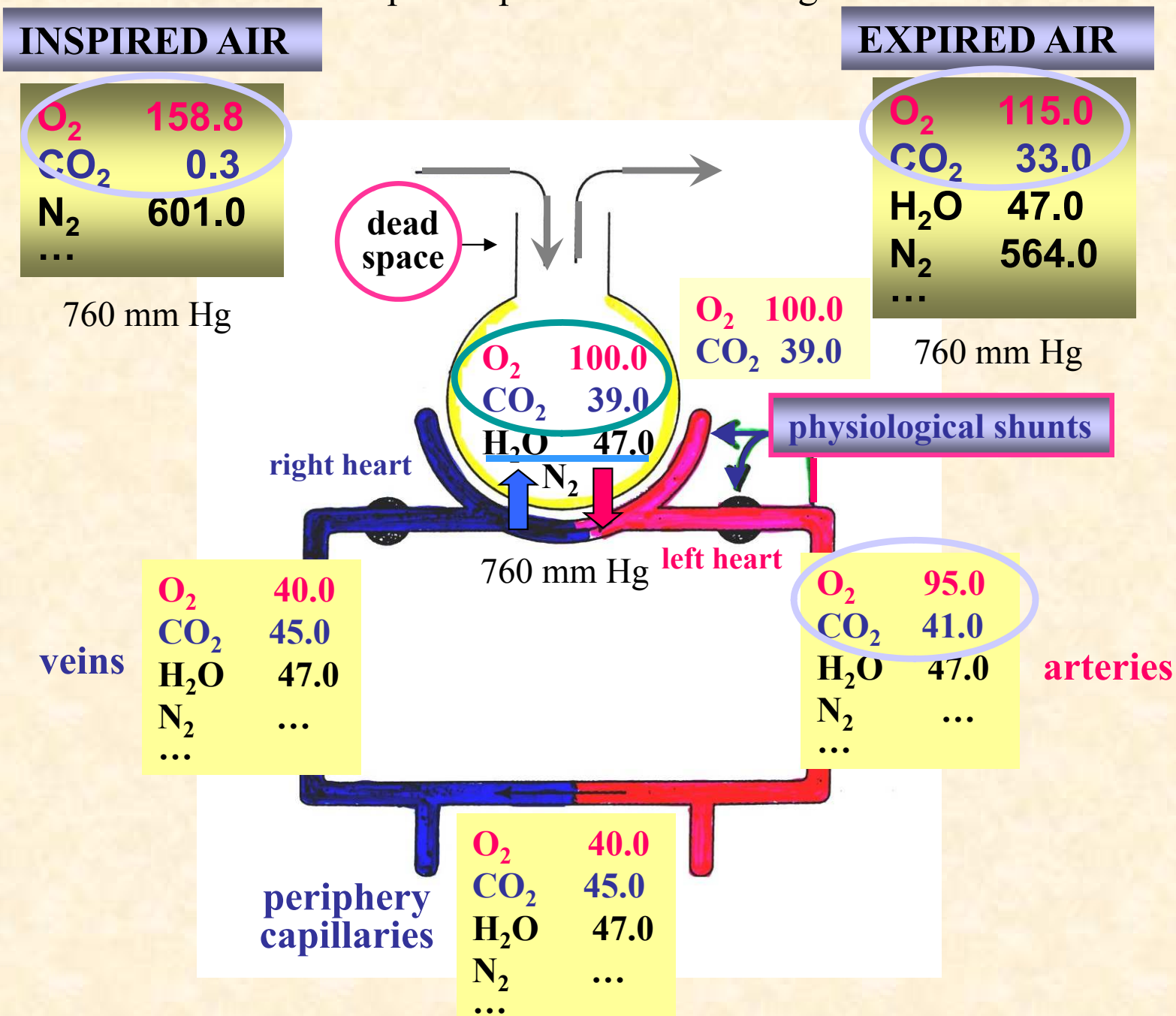
P_{N2} = 760 x 0.78 = ~593 mm Hg

P_{CO2} = 760 x 0.0004 = ~0.3 mm Hg

1 *kPa* = 7.5 *mm Hg (torr)*

COMPOSITION OF ALVEOLAR AIR

partial pressures in mm Hg

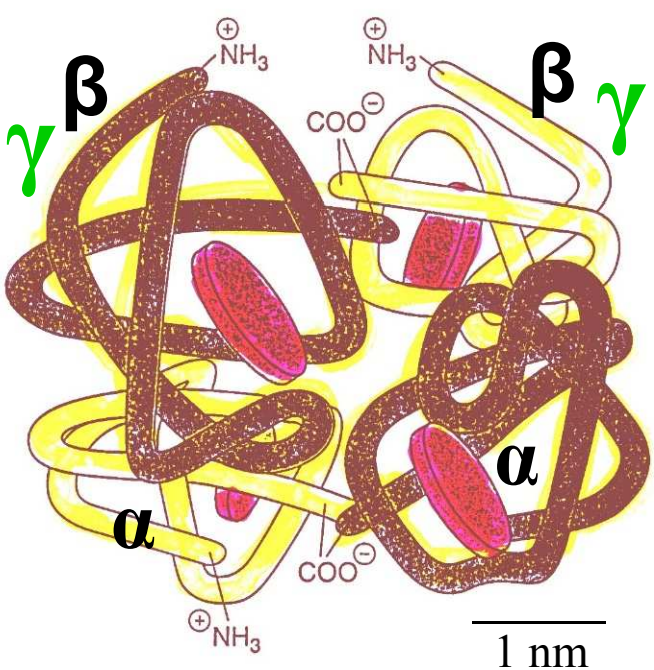


HAEMOGLOBIN

$Hb_4 + 4\ O_2 \leftrightarrow Hb_4O_8$

oxygenation

tetramer

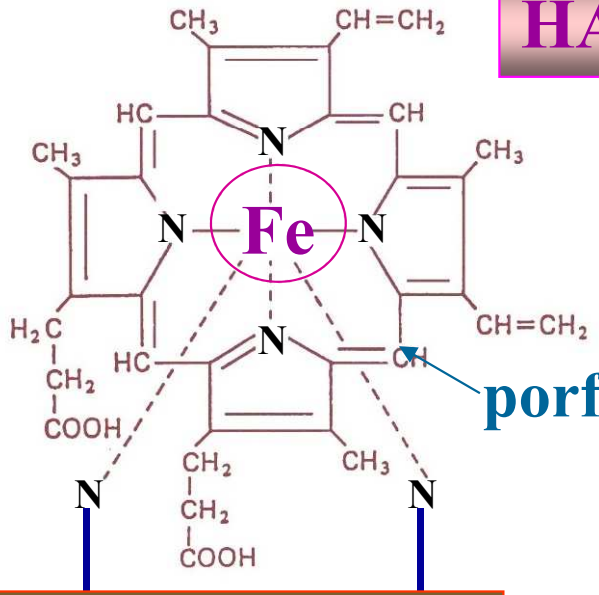


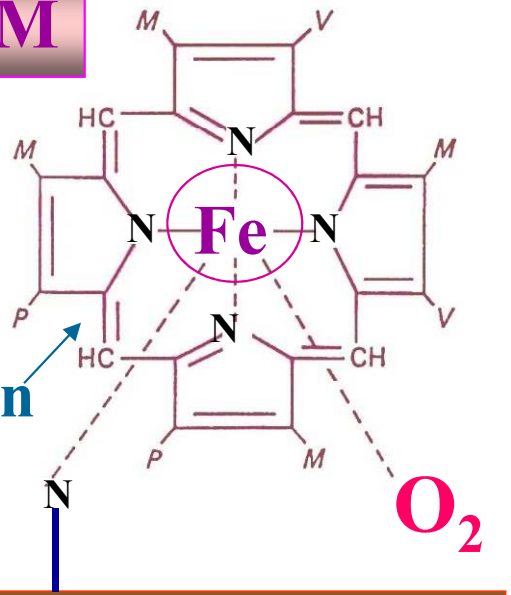
Fe^{2+}

HAEM

DEOXY

OXY





porfyrin

O_2

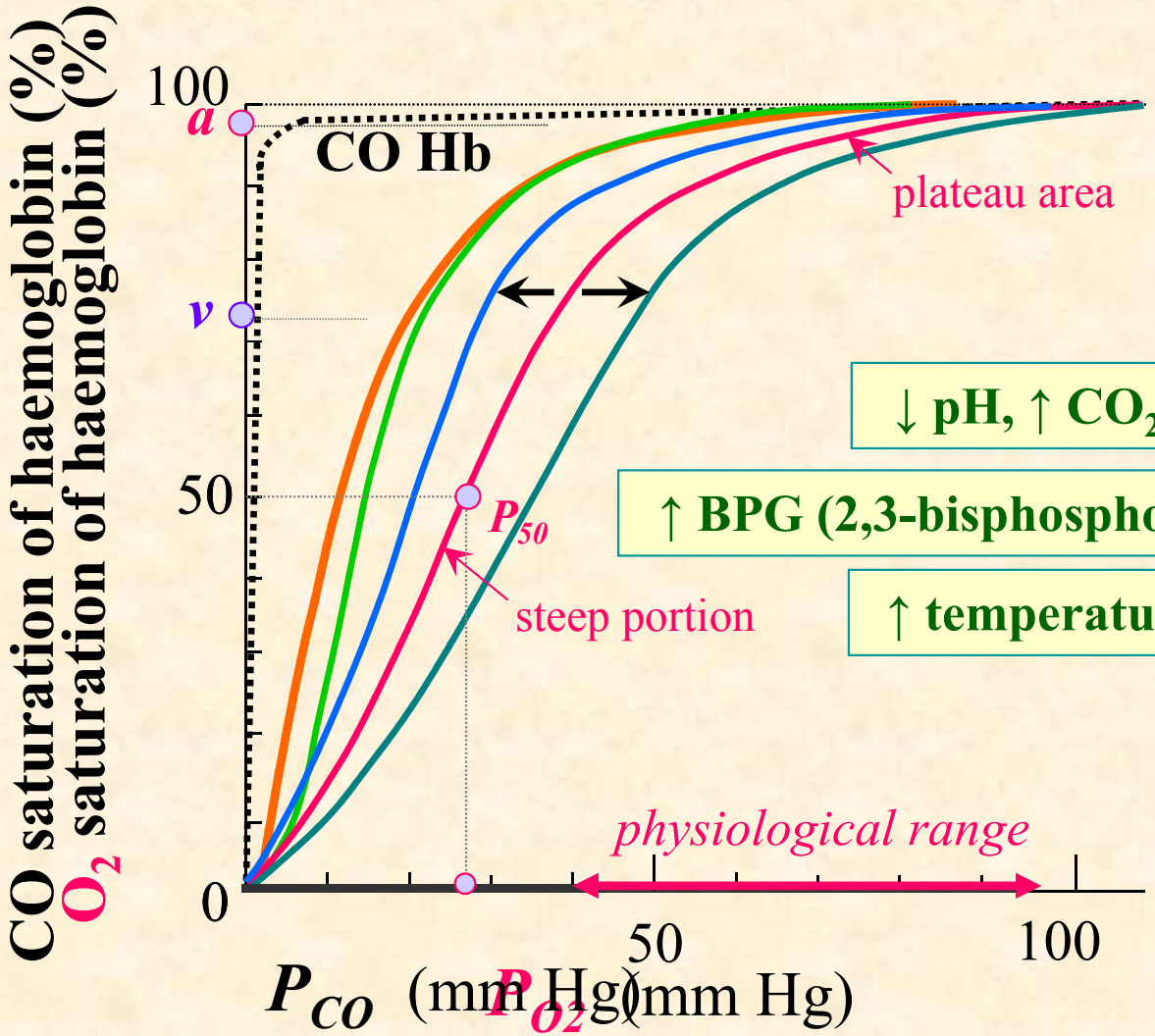
polypeptide chain

polypeptide chain

fetal Hb

Fe^{3+} (methaemoglobin) oxidation

O_2–HAEMOGLOBIN DISSOCIATION CURVE



BOHR´S EFFECT
(↓ pH, ↑CO_2)

↓ pH, ↑ CO_2

↑ BPG (2,3-bisphosphoglycerate)

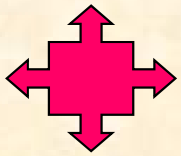
↑ temperature

fetal Hb

myoglobin

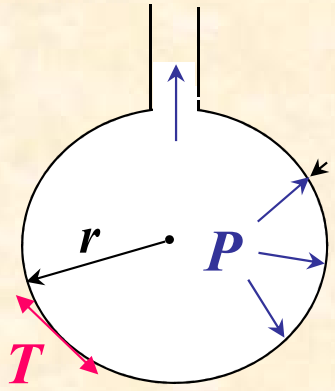
methaemoglobin

physically dissolved O_2 (1.4%)



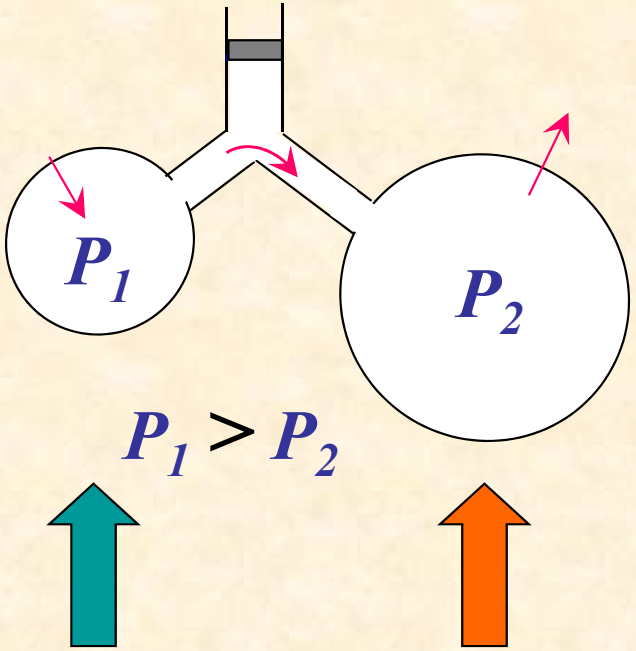
LAW OF LAPLACE

spherical structures



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

?



P pressure

r radius

T surface tension

PATHOLOGY

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

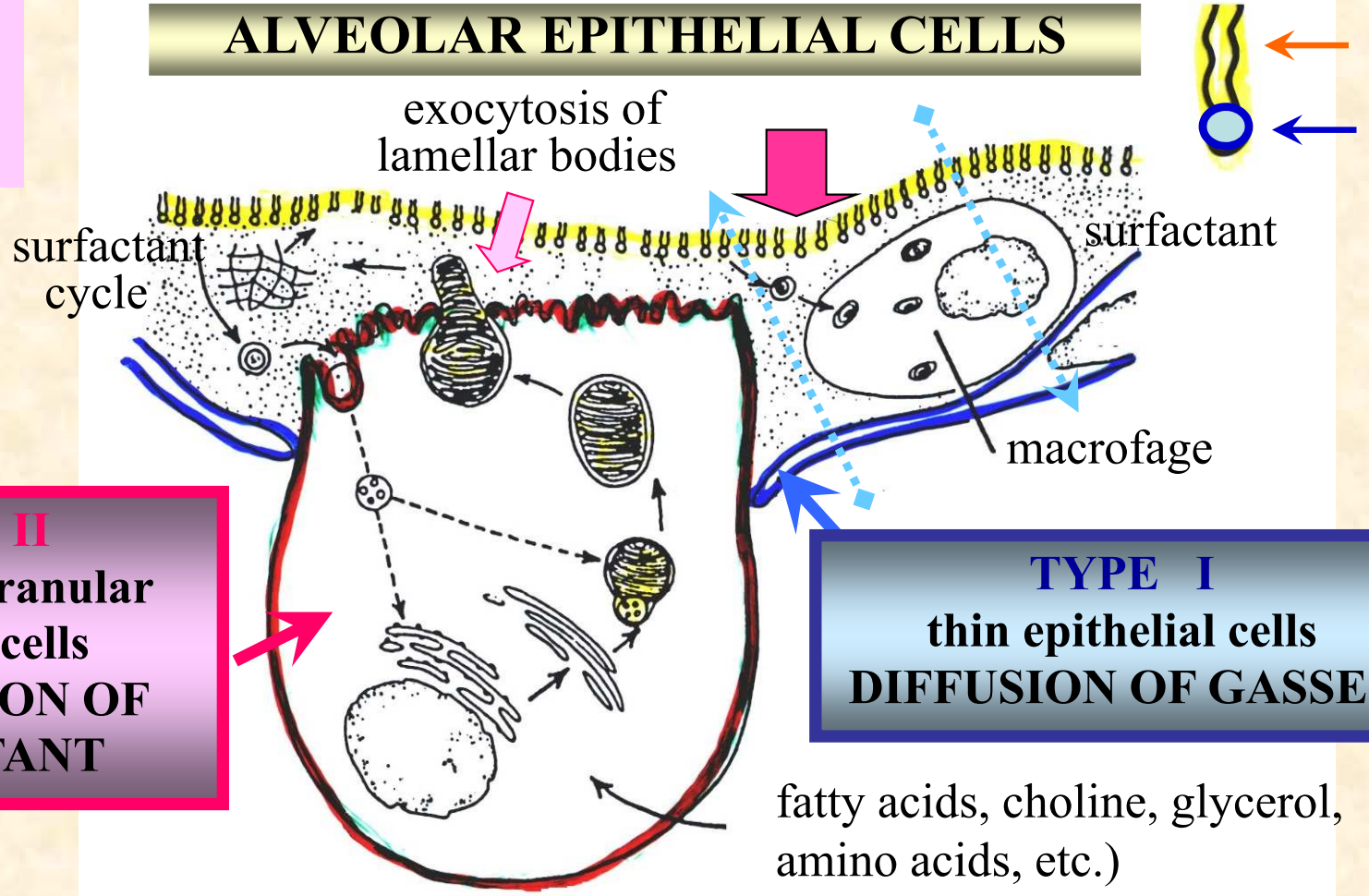
SURFACTANT

SURFACE TENSION LOWERING AGENT

EFFECT MAINLY IN THE EXPIRED POSITION

PHOSPHOLIPID
dipalmitoyl
fosfatidyl cholin

ALVEOLAR EPITHELIAL CELLS



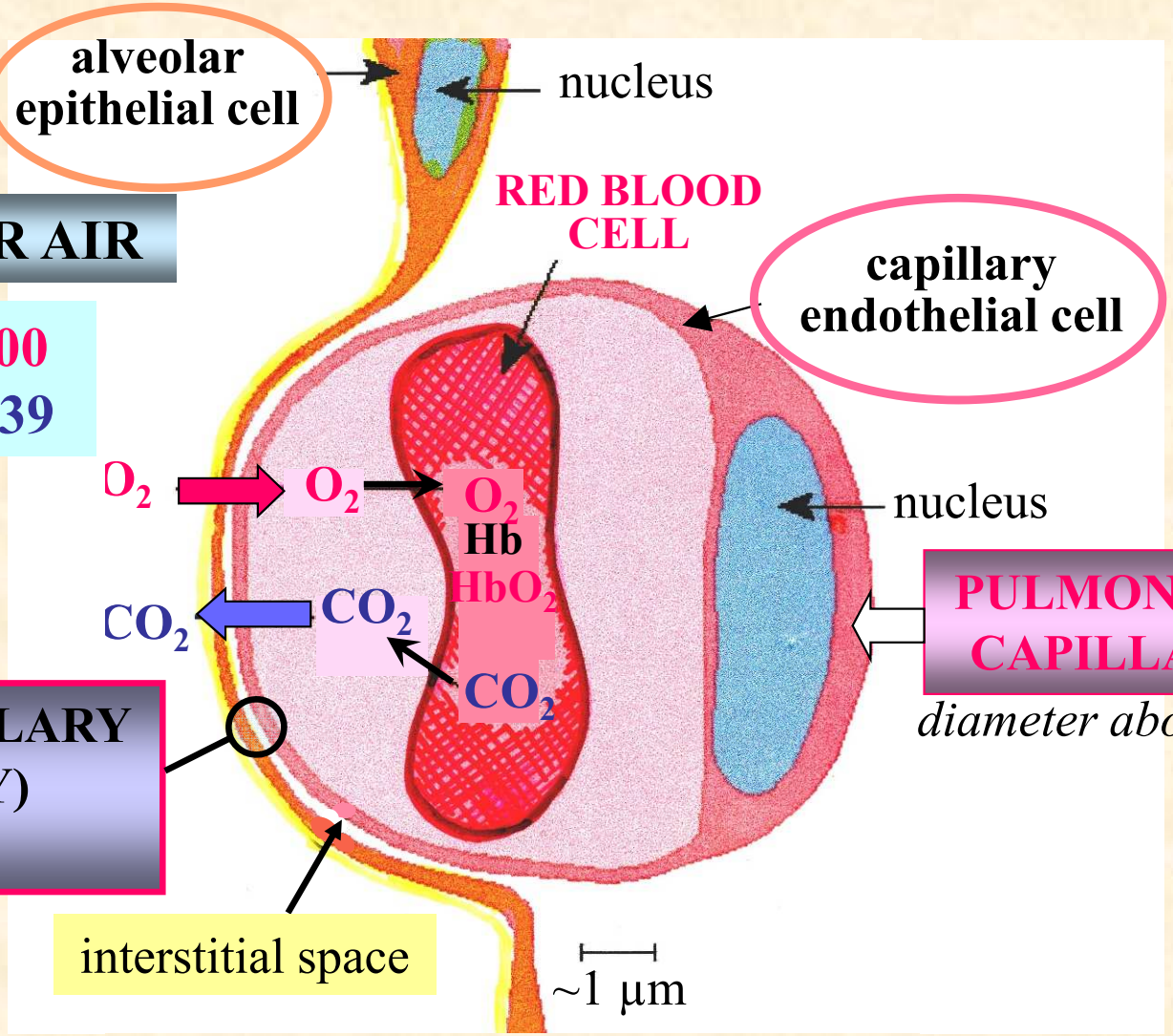
TYPE II
specialized granular epithelial cells
PRODUCTION OF SURFACTANT

TYPE I
thin epithelial cells
DIFFUSION OF GASSES

fatty acids, choline, glycerol,
amino acids, etc.)

ALVEOLAR-CAPILLARY (RESPIRATORY) MEMBRANE

DIFFUSION OF GASES



0.75 s

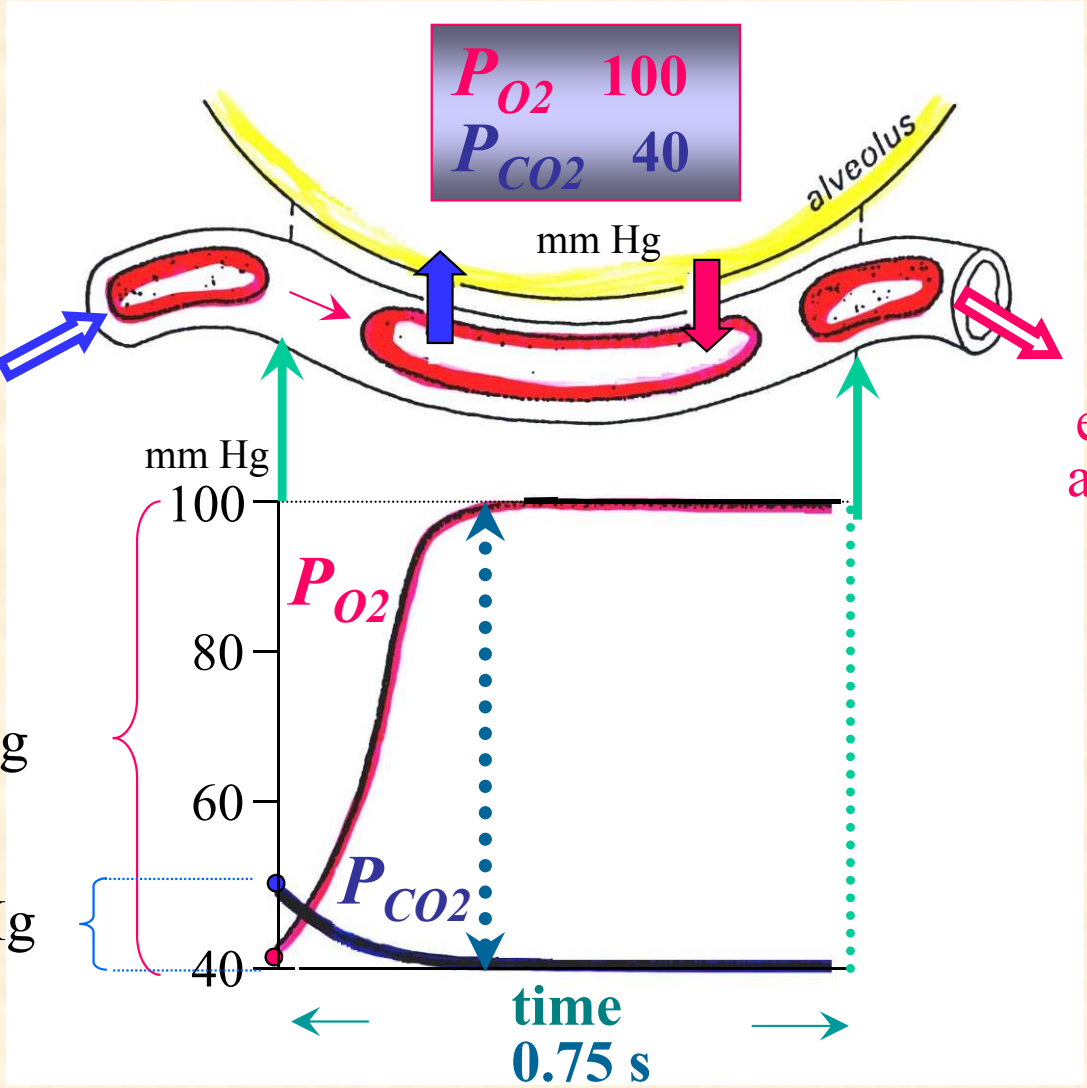
time interval of erythrocyte contact with respiratory membrane at rest

TIME COURSE OF CAPILLARY P_{O2} AND P_{CO2} DURING GRADUAL EQUILIBRATION WITH ALVEOLAR AIR

venous blood

P_{O2} 40
P_{CO2} 46

mm Hg



P_{O2} 100
P_{CO2} 40

mm Hg

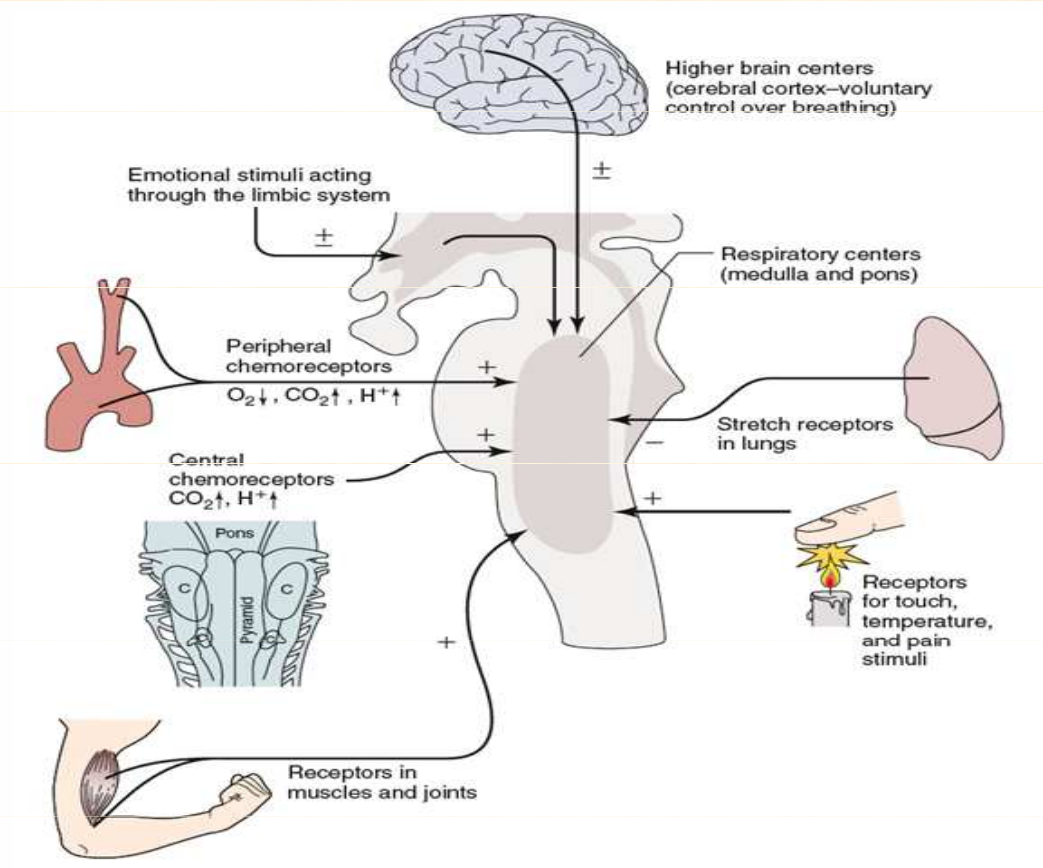
equalization with alveolar pressures

$\Delta P_{O2} \cong 60$ mm Hg

$\Delta P_{CO2} \cong 6$ mm Hg

time interval of contact of erythrocyte with respiratory membrane at rest

Control of ventilation



https://sleep.sharepoint.com/siteimages/Chapter%203.png

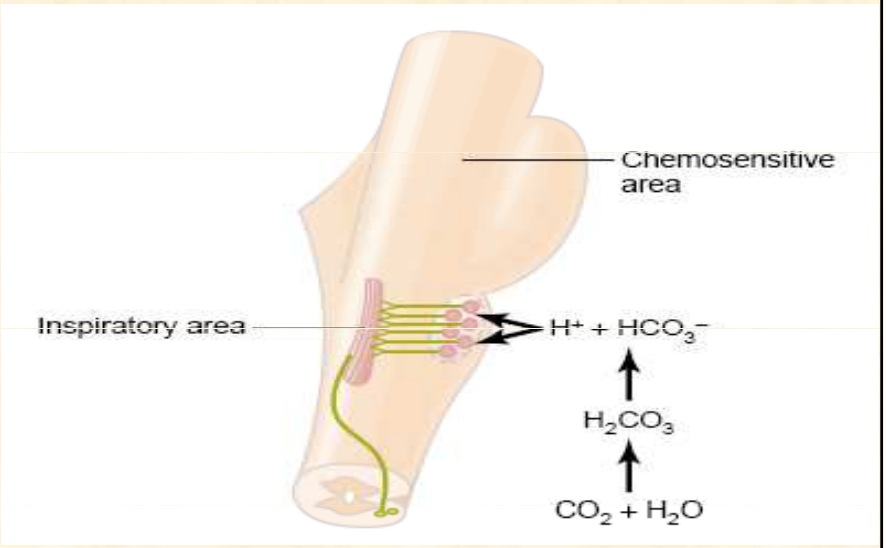
- **Breathing is an automatic process that takes place unconsciously. Automaticity of breathing comes from regular (rhythmic) activity of groups of neurons anatomically localized in the medulla and its vicinity.**

- 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.

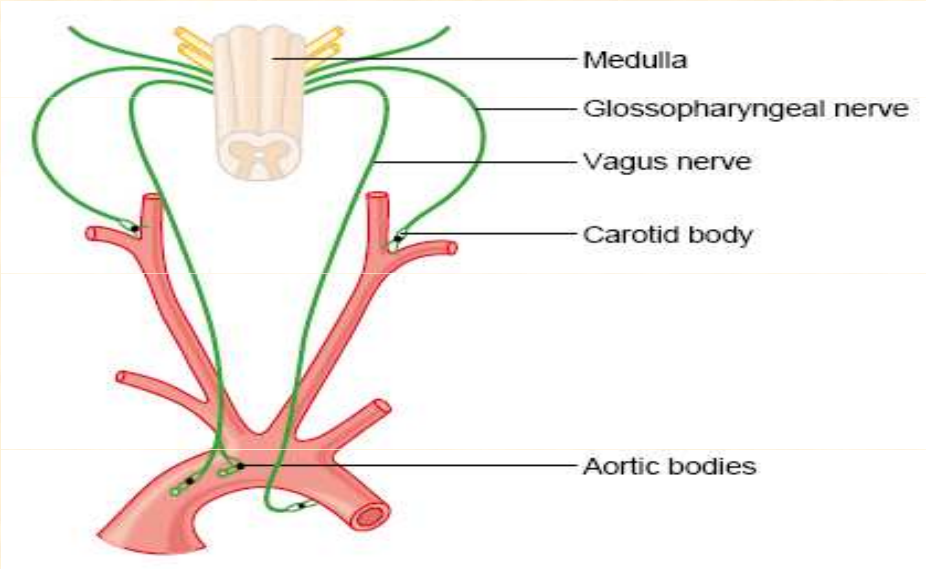
Chemical factors affecting the respiratory center:

Central chemoreceptors

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



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

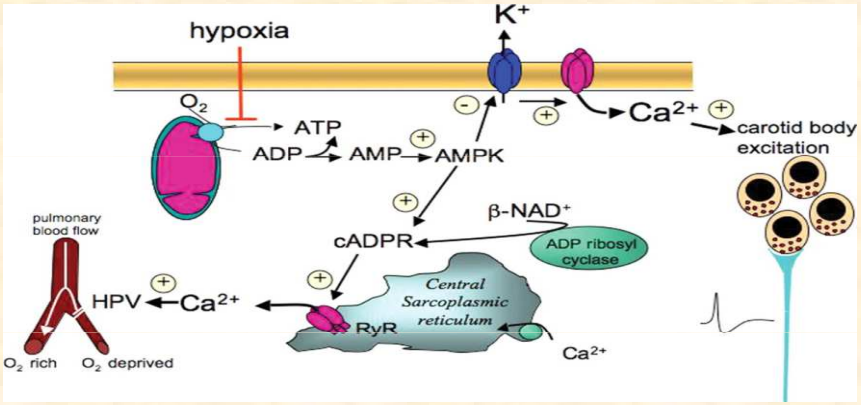


Peripheral chemoreceptors

– 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,

Modulation of respiratory output

Major parameters for feedback control – classical gases:pO2, pCO2, pH

In additin to these, the respiratory system receives input from two other major sources:

1. variety of stretch and chemical/irritant receptors that monitor the size of airways and the presence of noxious agentsreceptors in respiratory system

2. Higher CNS centers that modulate respiratory activity for the sake of nonrespiratory activities

Irritants receptors on mucose of respiratory system – rapidly adapting
Stimulus: agens - chemical substances (histamin, serotonin, prostaglandins, ammonia, cigarette smoke).
Respons: increase mucus secretion, constriction of larynx and brochus

C-fibre receptors (juxtacapillary=J receptors)– free nerve ending of n.vagus (unmyelinated axon) in intersticium of bronchus and alveolus;
Stimulus: Mechanical irritans (pulmonary hypertension, pulmonary oedema)+chemical
Response: hypopnoe, rapid shallow breathing, bronchoconstriction, cough

Stretch receptors slowly adapting (mechanoreceptors in tracheobronchial tree that detect the changes in lung volume by sensing the stretch receptors of the airway wall), inform to brain about the lung volume to optimize respiratory; its irritants triggered decrese activity of respiratory centre – **Hering-Breuer´s reflexes**. (protecting the lungs from overinflation/deflation)

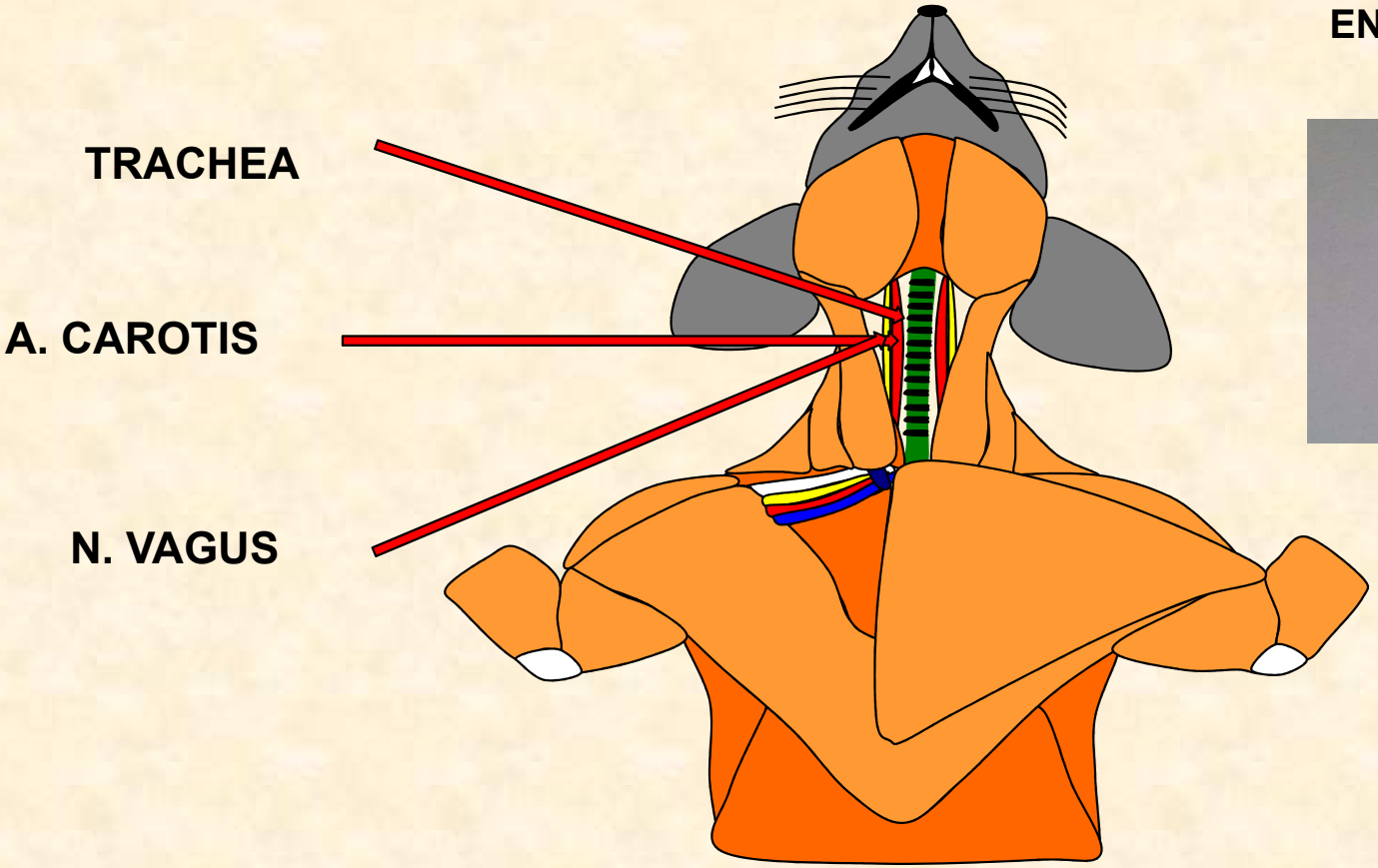
Baroreceptors – suppresses activity of respiratory centre

Irritants of **proprioreceptors of muscles, tendons** during active and pasive movements of limbs
Influenced activity of respiratory neurons (increase minute ventilation during work load)

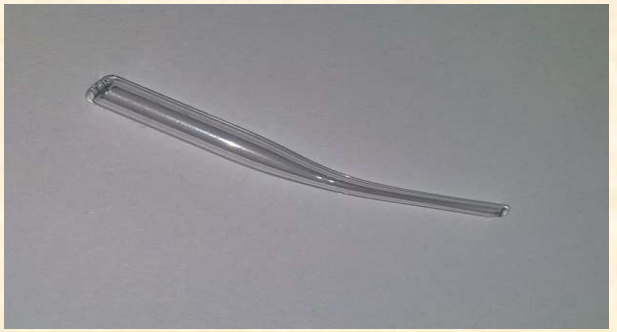
Limbic system, hypothalamus – strong pain, emotion
Tractus corticospinalis =cortex – activated RC during work load

temperature

- Hering – Breuer ´s reflex in animal experimentH

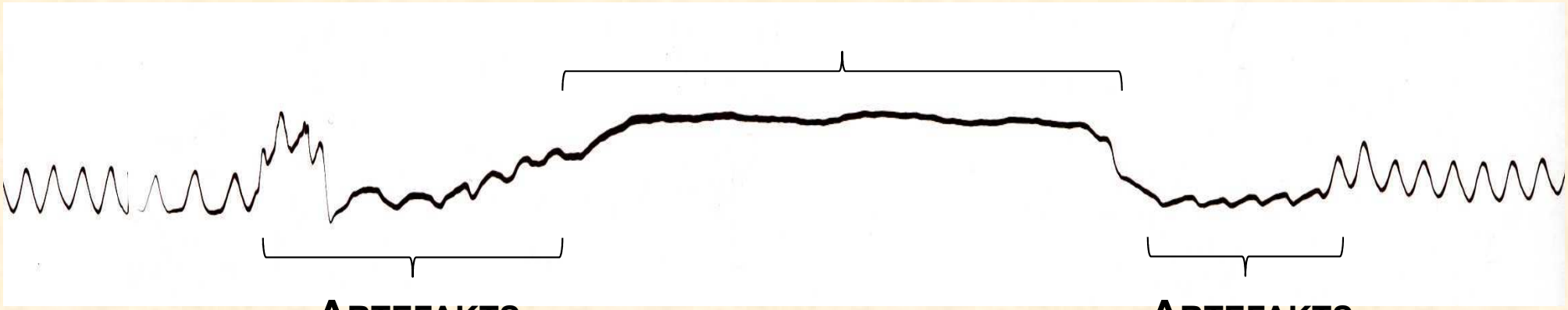


ENDOTRACHEAL CANNULA



HERING-BREUER REFLEX

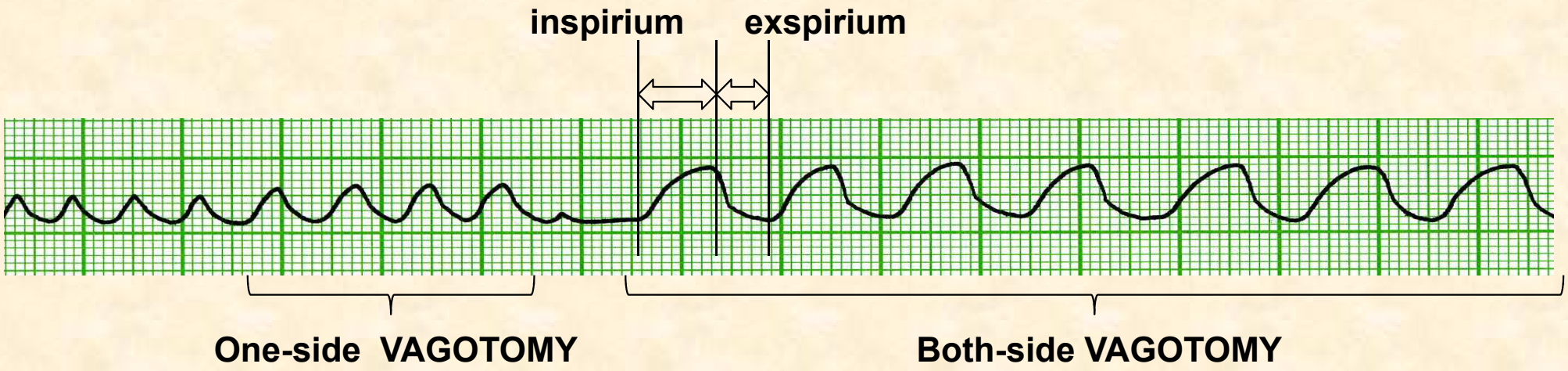
REFLEX STOP BREATHING



ARTEFAKTS

ARTEFAKTS

Changes of breathing after VAGOTOMY



Hypoxia, hypoxemia

- Hypoxia is a general name for a lack of oxygen in the body or individual tissues.
- Hypoxemia is lack of oxygen in arterial blood.
- Complete lack of oxygen is known as anoxia.

The most common types of hypoxia:

1. Hypoxic - physiological: stay at higher altitudes, pathological: hypoventilation during lung or neuromuscular diseases
2. Transport (anemic) - reduced transport capacity of blood for oxygen (anemia, blood loss, CO poisoning)
3. Ischemic (stagnation) - restricted blood flow to tissue (heart failure, shock states, obstruction of an artery)
4. Histotoxic - cells are unable to utilize oxygen (cyanide poisoning - damage to the respiratory chain)

Hypercapnia

- Hypercapnia - increase of concentration of carbon dioxide in the blood or in tissues that is caused by retention of CO_2 in the body
- possible causes: total alveolar hypoventilation (decreased respiration or extension of dead space)
- mild hypercapnia (5 -7 kPa) causes stimulation of the respiratory center (therapeutic use: pneumoxid = mixture of oxygen + 2-5% CO_2)
- hypercapnia around 10 kPa - CO_2 narcosis - respiratory depression (preceded by headache, confusion, disorientation, a feeling of breathlessness)
- hypercapnia over 12 kPa - significant respiratory depression - coma and death.

THANK YOU FOR YOUR ATTENTION