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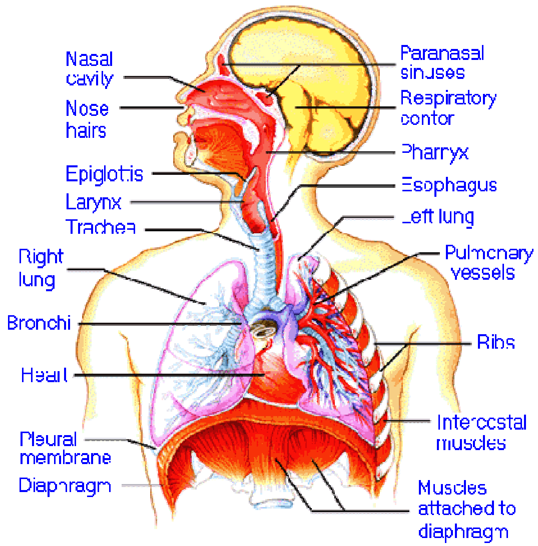

Lectures on Medical Biophysics

Biophysics of breathing. Spirometry

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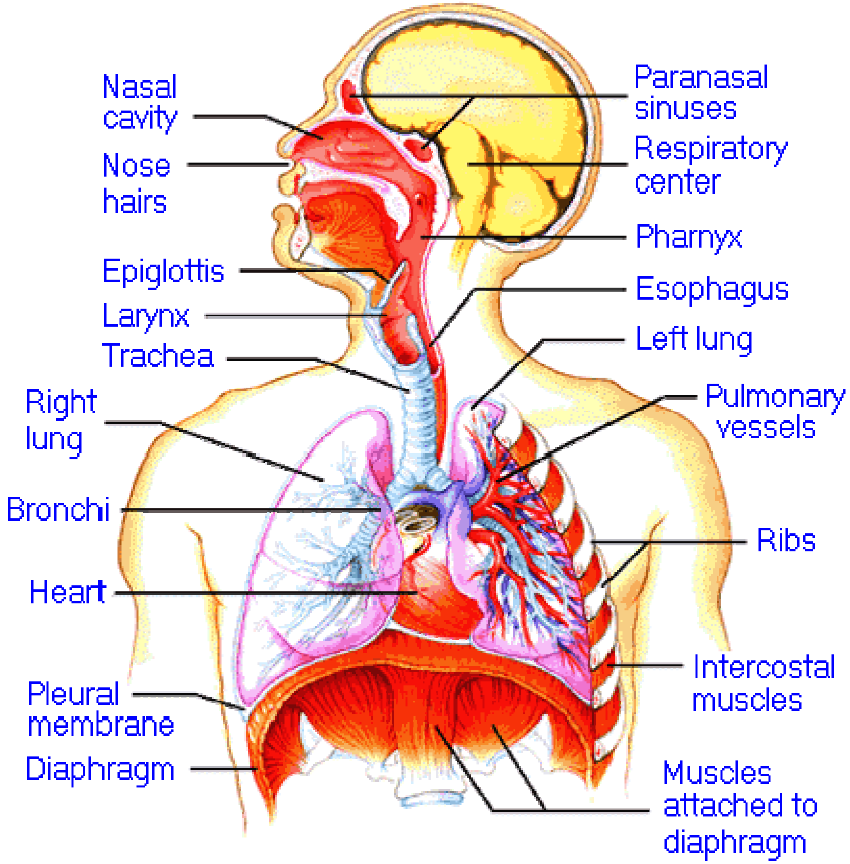
Lecture outline

- Mechanisms of gas exchange between organism and surroundings (respiratory movements – mechanics of breathing, diffusion and dissolution of gases)
- Respiratory volumes and capacities
- Respiratory resistances
- Respiratory work
- Spirometry
- Some biophysical aspects of breathing

Respiratory movements

These movements are done mainly by intercostal muscles and diaphragm:
Thoracic breathing (predominant in women) and abdominal breathing (predominant in men)



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Dle: http://www.medem.com/MedLB/article_detaillb.

Diffusion of O_2 and CO_2 in plasma

Bunsen coefficients of solubility (α) for gases in blood under normal body temperature. The unit of solubility is (ml of gas under normal temperature and pressure) $*$ (ml of blood)$^{-1}$ $*$ (101.3 kPa)$^{-1}$	
CO_2	0.52
CO	0.018
N_2	(Water: 0.013; Fat: 0.065)
O_2	0.022

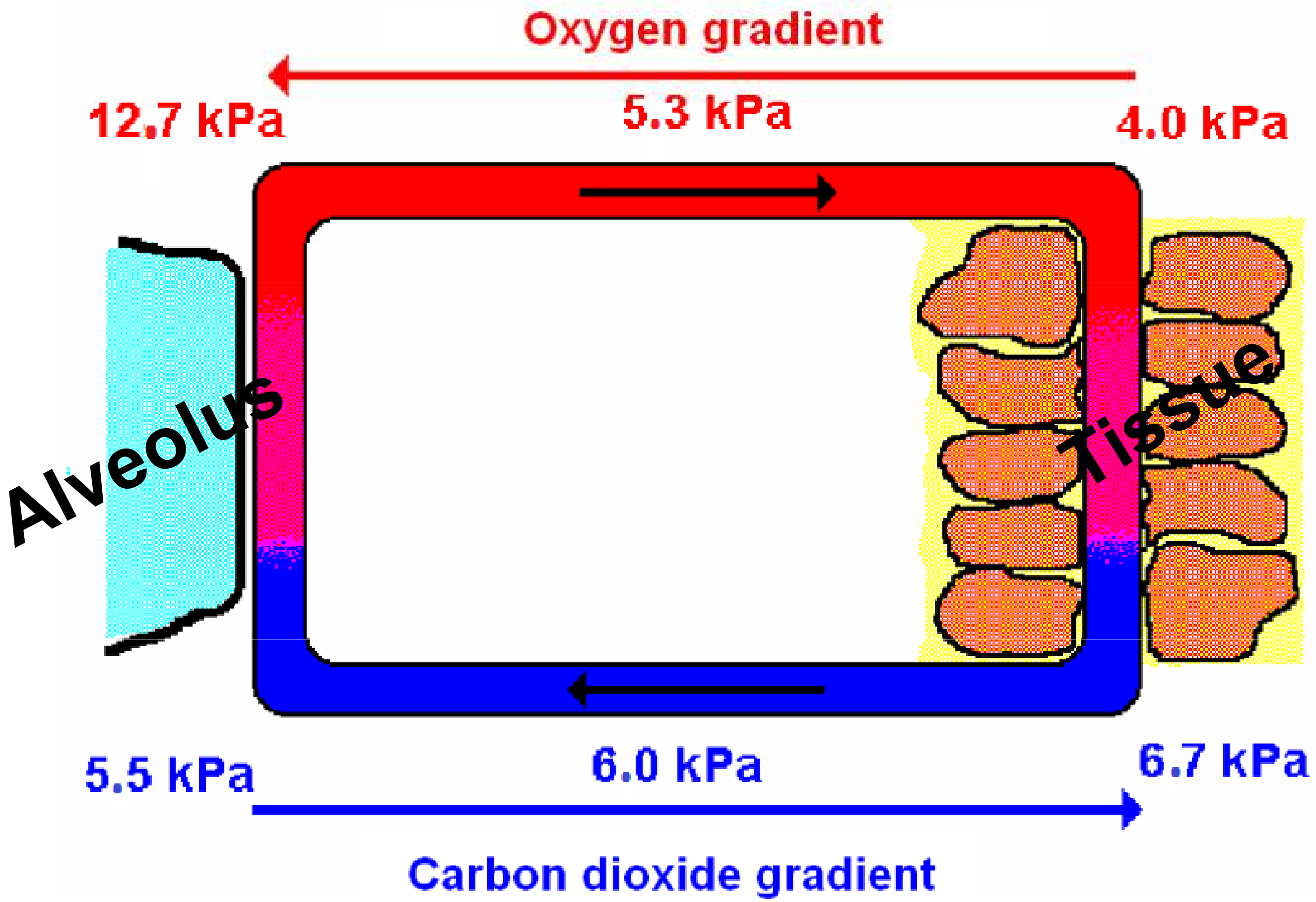
- Molecular weights:
  $M_{O2} = 32$
  $M_{CO2} = 44$

$$\frac{D_{CO_2}}{D_{O_2}} = \frac{\alpha_{CO_2}}{\alpha_{O_2}} \cdot \sqrt{\frac{M_{O_2}}{M_{CO_2}}} = 20.9$$

Gas exchange

Medium	Way of transport	pO_2 (kPa)	pCO_2 (kPa)
alveoli	streaming	**13.3**	**5.2**
alveolar-capillary wall	diffusion	**-**	**-**
Blood circulation: arteries veins	streaming	 **12.7** **5.3**	 **5.5** **6.0**
Capillary wall cellular membrane	diffusion	**-**	**-**
Living cell		**4.0**	**6.7**

Exchange of O_2 and CO_2



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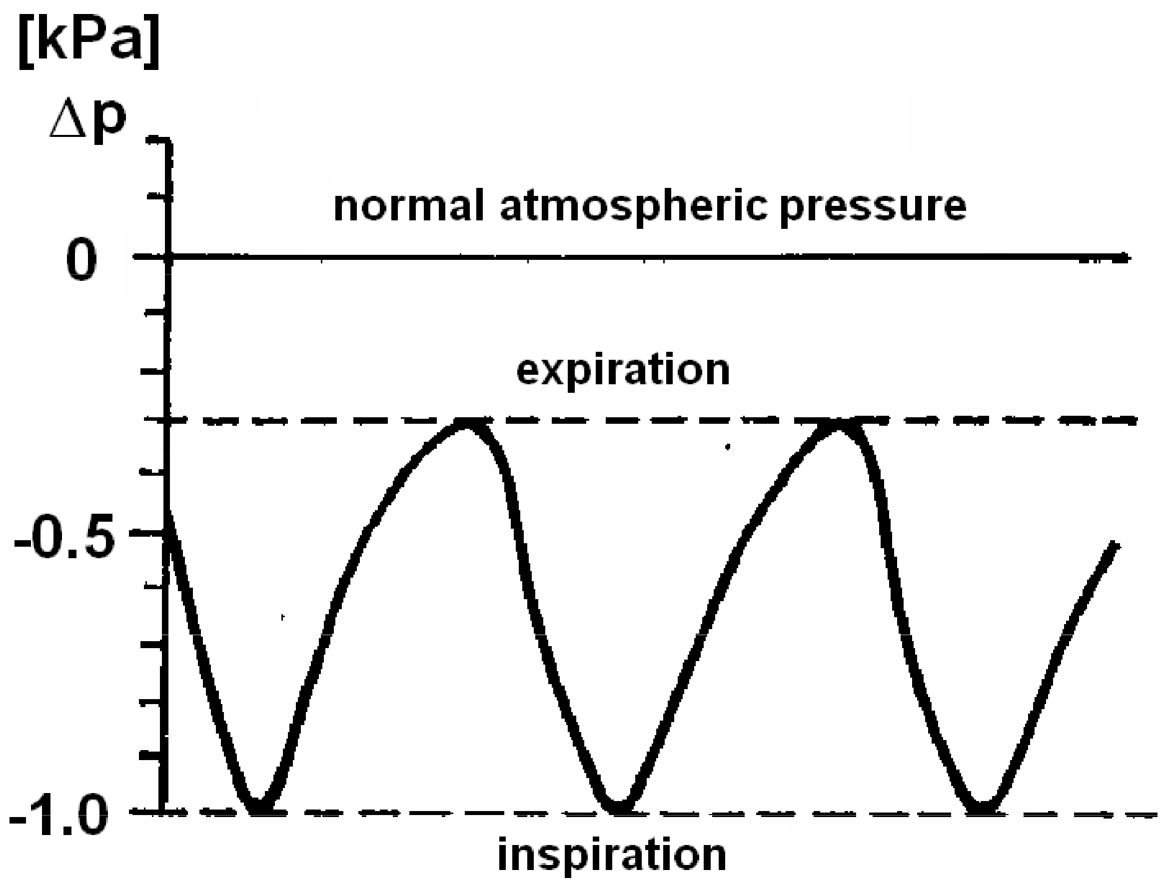
Changes of negative pleural pressure during respiration



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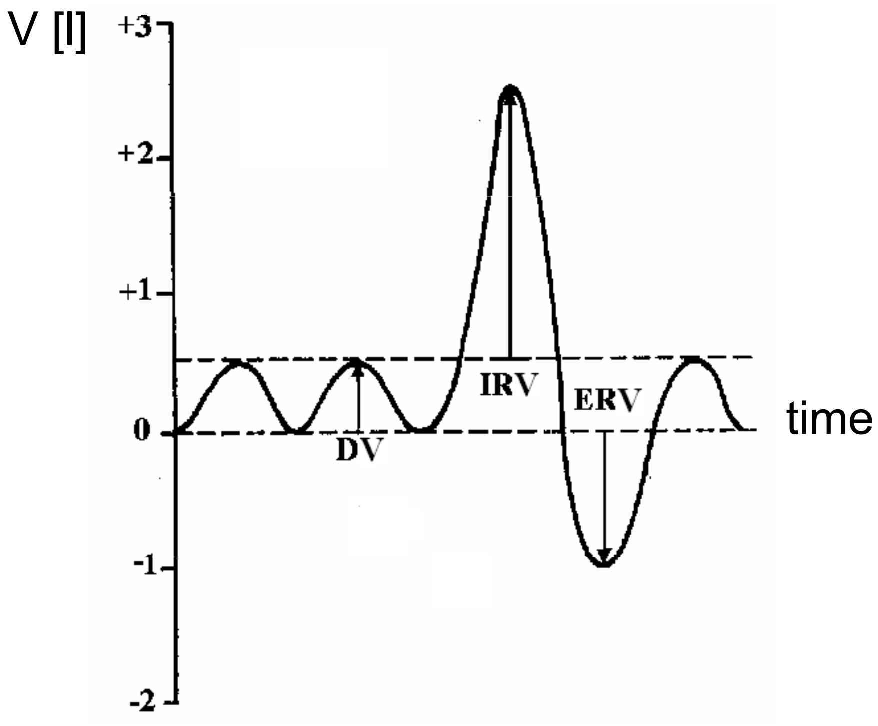
Respiratory volumes and capacities

Air in airways – death space - 150 ml
Residual air volume in alveoli - RV - 1 l
Expiration reserve volume - ERV – 1.5 l
Resting (tidal) respiratory volume - TV - 0.5 l
Inspiration reserve volume - IRV – 2.5 l

Vital capacity
VC = ERV + TV + IRV
Functional residual capacity
FRC = RV + ERV

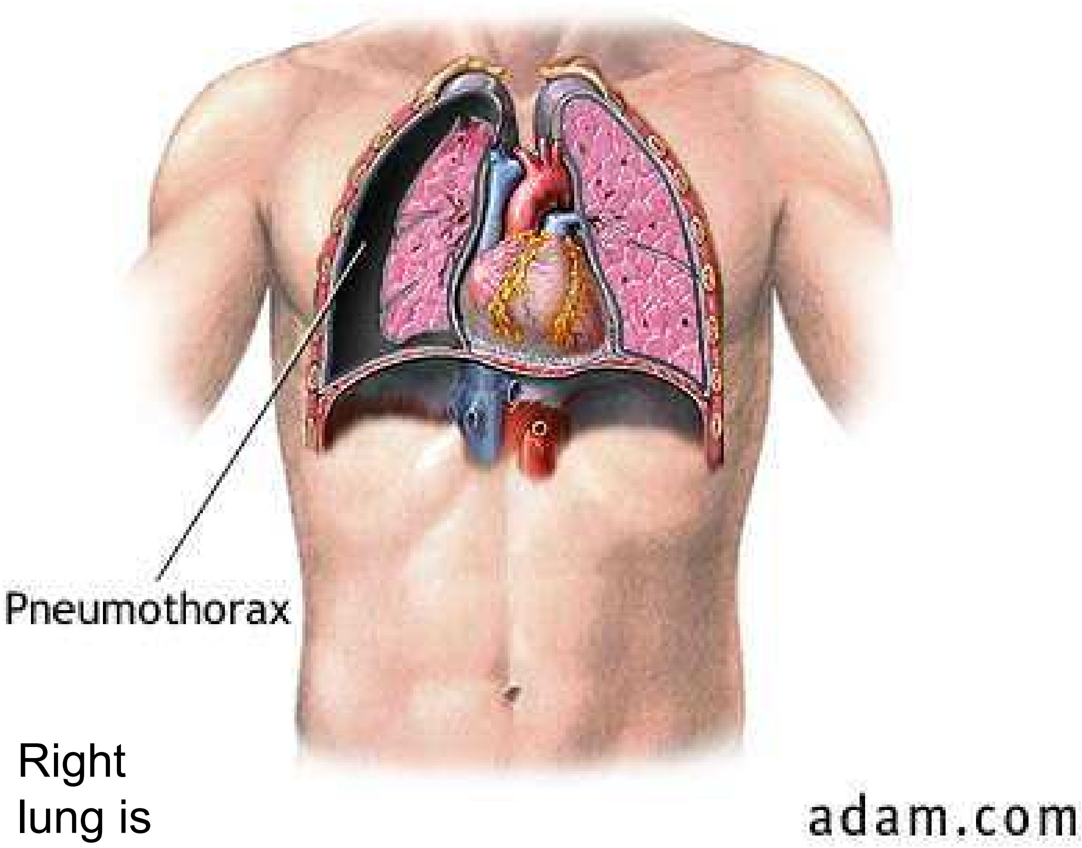
Measure of lungs ventilation: minute volume

MV = Respiratory volume × breathing rate
[$l \cdot min^{-1}$]



Example of a spirogram

Pneumothorax



Right
lung is
collapsed

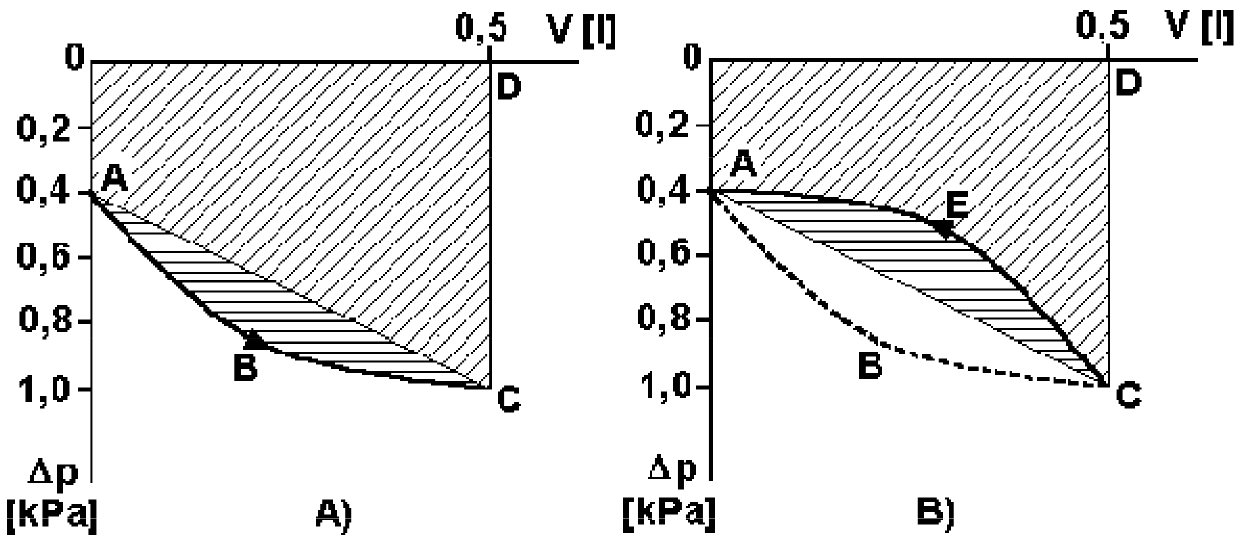
•http://www.pennhealth.com/health/health_info/Surgery/graphics/Pneumothorax_2.jpg

Respiratory resistances

- Elastic resistance of lungs and chest is given by tension of elastic fibres in pulmonary tissue. The surface tension of alveoli has similar effect.
- Non-elastic resistance of tissues (also tissue viscous resistance). It arises due to friction of pulmonary tissues, chest, respiratory muscles and organs of abdominal cavity.
- Flow resistance of airways – complex of resistances caused by air flow (effect of air viscosity, incl. turbulences). It increases substantially when the airways are narrowed.

Respiratory work (picture to consider)

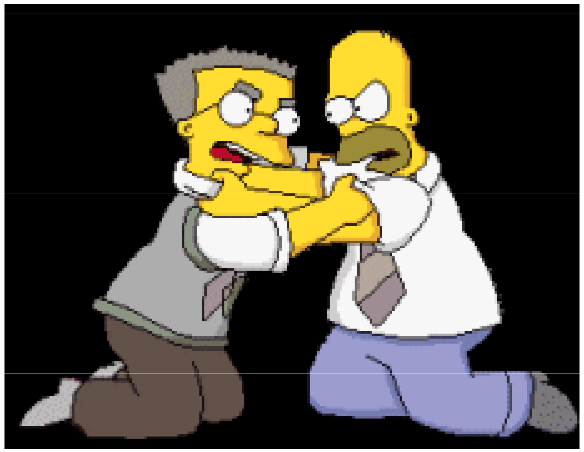
This work is necessary to overcome all the respiratory resistances:
W = p∆V
p is the difference of intrapulmonary and pleural pressures, ∆V is the breathing volume



Respiratory work. A) – during inspiration, B) – during expiration. Area 0ACD0 – elastic work done at the expense of body energy (during inspiration) or at the expense of potential energy of distended elastic tissues (during expiration). Area ABCA represents active inspiration work against the non-elastic resistance. Area ACEA represents the work against the non-elastic resistance during expiration at the expense of body energy (after Pilawski).

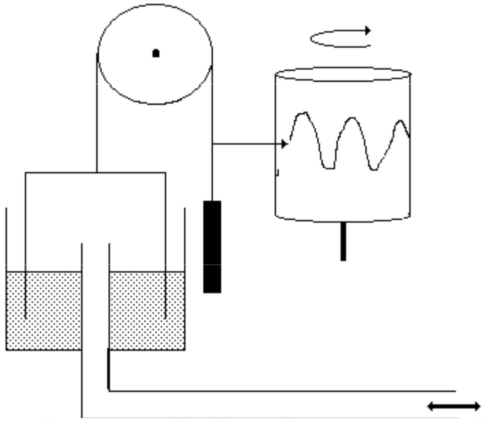
How to calculate respiratory work?

At rest:
minute volume MV = 7 l
breathing rate BR = 14 min^{-1}
pressure p = 0.7 kPa
respiratory volume V = 0.5 l ($5 \cdot 10^{-4}$ m^3)
work W = 0.35 J – for one inspiration
294 J per 1 hour



At great load:
MV = 200 l
BR 100 min^{-1}
p = 0,7 kPa
V = 2 l ($2 \cdot 10^{-3}$ m^3)
W = 1.4 J - for one inspiration
8400 J per 1 hour

Measurement of respiratory volumes and speeds - spirometry

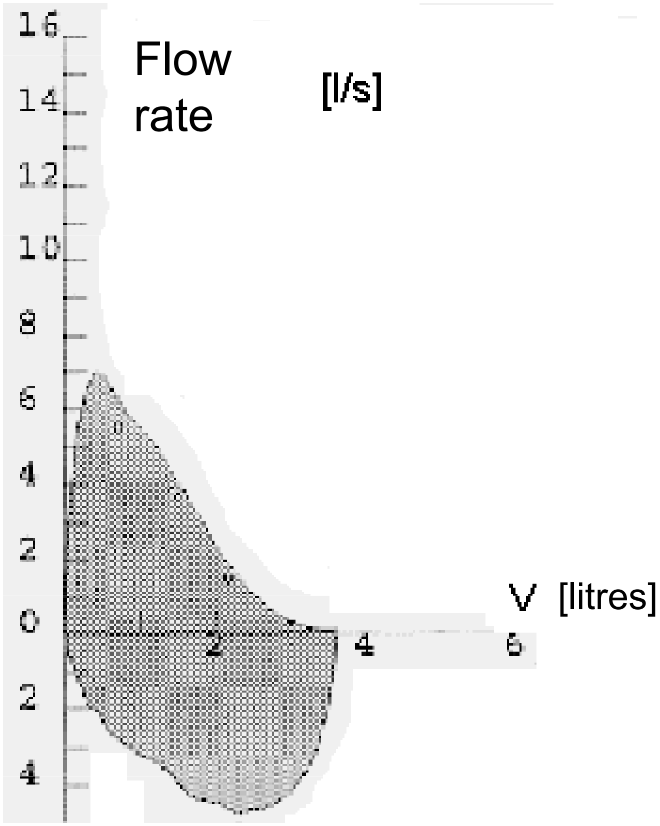


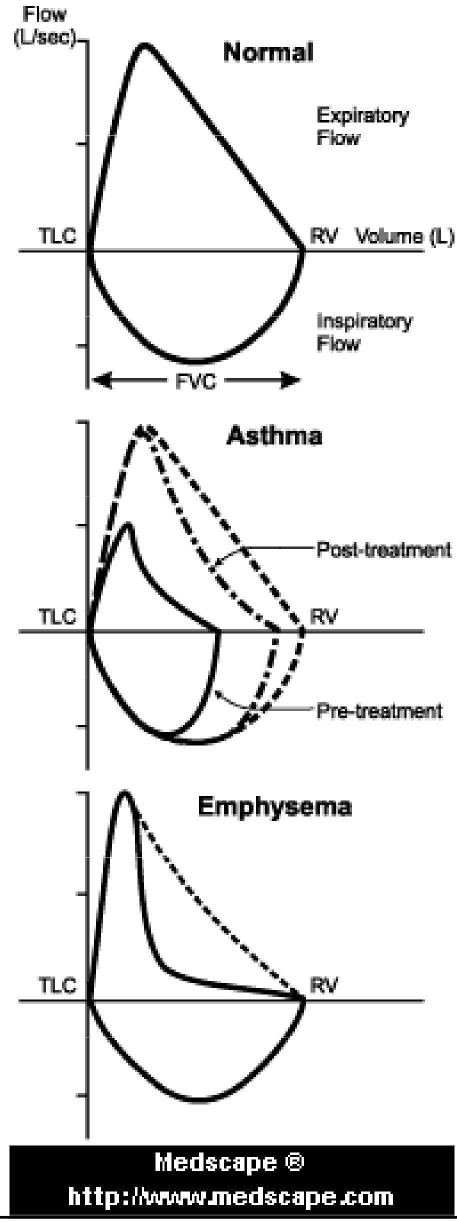
Spirogram

We can measure the dependence of **volume on time**

or

Flow rate on volume





Some biophysical aspects of breathing

– Physical properties of lungs and their manifestations in some areas of diagnostics and therapy:
  - The lungs represent the largest contact area with ambient medium
  - Many functions of organism can be influenced by rate or depth of breathing (hyperventilation)
  - Breathing movements can disturb e.g. X-ray diagnostics
  - Lungs have negative contrast in X-ray images
  - Physical properties of alveoli are similar to bubbles – lung tissue can be impaired by cavitation phenomena (risk in ultrasound diagnostics and lithotripsy)

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