Breathing I: Mechanics of lung ventilation

vaclav.hampl@lf2.cuni.cz

http://fyziologie.lf2.cuni.cz
http://vh.cuni.cz

CHARLES UNIVERSITY
Second Faculty of Medicine

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And the Lord God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul. (Genesis 2, 7)

And the rib, which the Lord God had taken from man, made he a woman, and brought her unto the man. (Genesis 2, 22)

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Oxygen

Joseph Priestley 1774

Antoine Laurent Lavoisier

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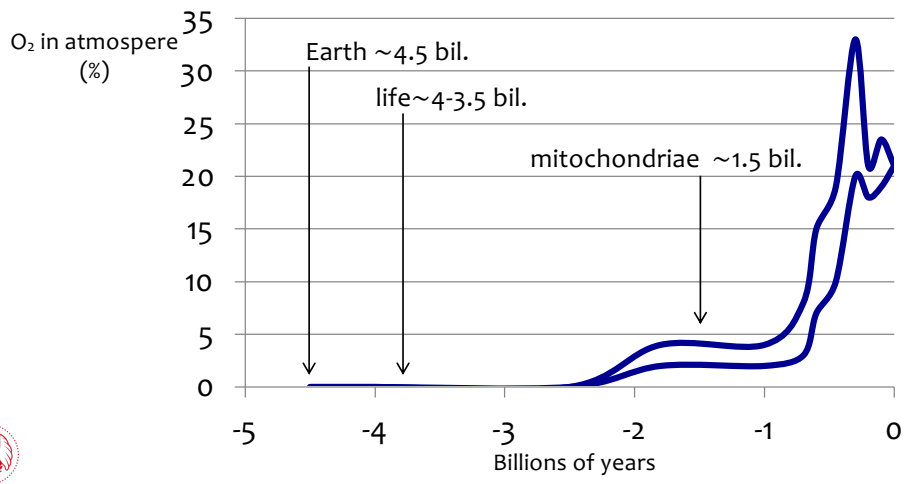
O_2 in atmosphere only recently



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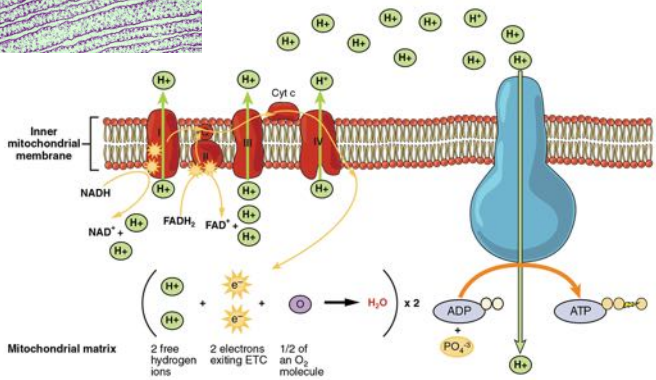
Mitochondria

endosymbiosis -1.5 bil years



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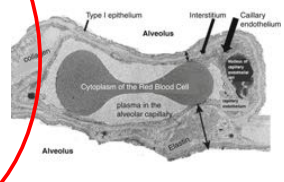
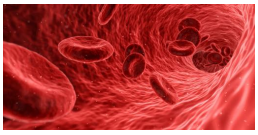
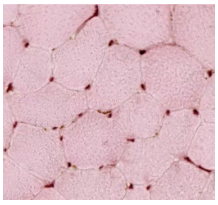
Transport of O_2 & CO_2 („blood gases“) in the body

convection ⇄ diffusion ⇄ convection ⇄ diffusion







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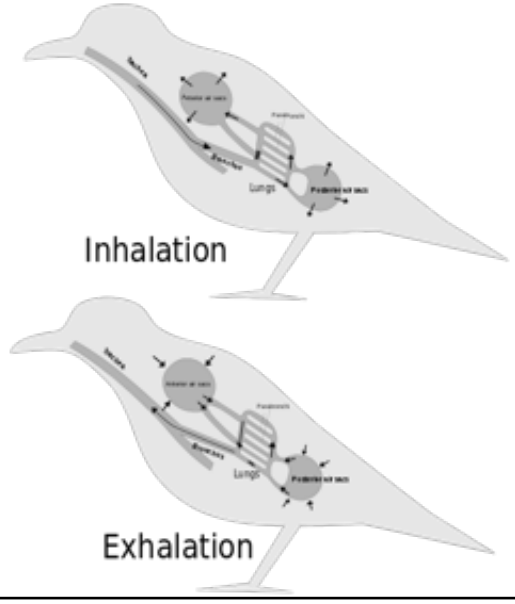
Breathing in vertebrates

- amphibians – „swallowing“ air + skin
- reptiles
  - dinosaurs – similar to birds
  - others – similar to mammals
- birds – parabronchi + air sacs (7-9)
- mammals - alveoli



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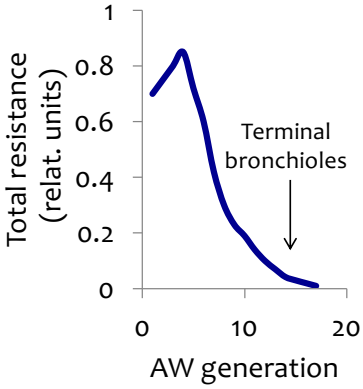
Breathing in mammals

- branching airways (total resistance↓)
- alveoli (large surface area)
- diffusion (short diffusion distance)
- perfusion
- <u>ventilation</u>:
  - active inspiration (negative pressure)
    - **<u>diaphragm</u>**, external intercostal muscles
  - passive resting exhalation
    - chest weight, lung elasticity



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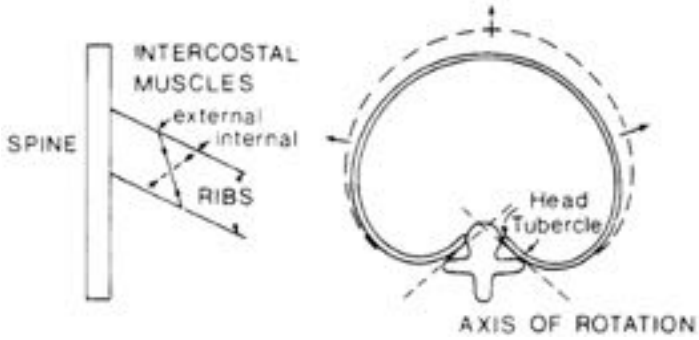

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Resting lung position (end-expiration)

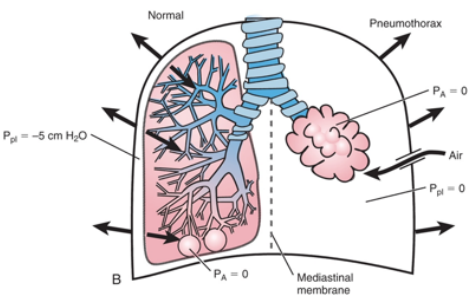
- lung „elastic recoil“

x

- chest tendency to expand

⇓

- slight negative pressure in intrapleural space (P_{IP}<P_B)
  (P_{IP} ~ -5 cmH_2O) *(1 cmH_2O ~ 0.75 ~ mmHg 0.1 kPa)*



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Interpleural space

- very thin
- filled with fluid (~8-10 ml)
  - non-compressible – transduction of pressures
- pressure measured in esophagus
- in mammals absent only in elephants (pleurae connected by loose ligament)

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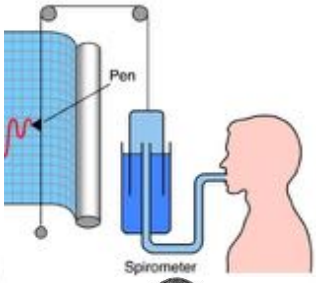
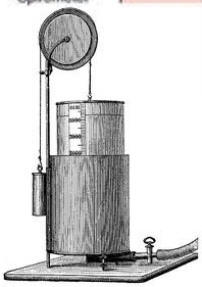
Spirometry

- Ventilatory volumes & capacities
  - V_T ~ 0.5 l
  - IRV ~ 2.5 l
  - ERV ~ 1.5 l
  - RV < 2 l
  - TLC, VLC, FRC
- Breath flow velocity





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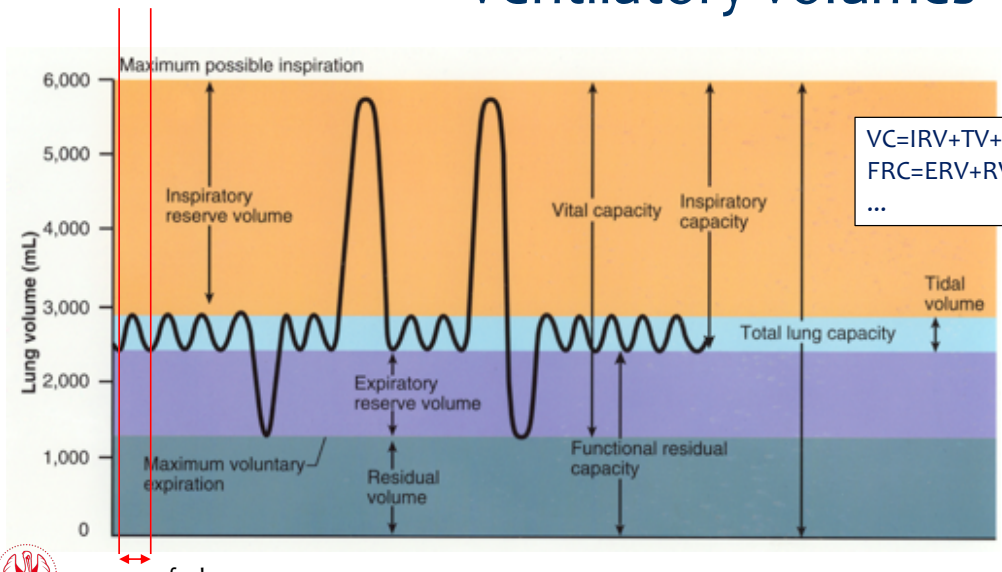
Ventilatory volumes



VC=IRV+TV+ERV
FRC=ERV+RV
...

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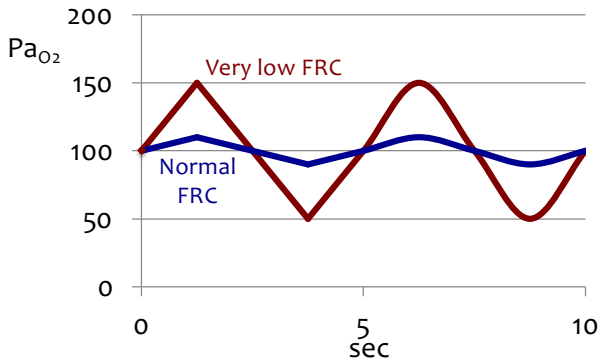
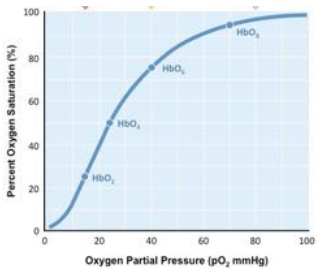
Why RV?

- prevents collapse of airways & alveoli (→ compliance)
- buffers Pa_{O_2} extremes during breathing cycle (perfusion is steady → relatively stable Pa_{O_2})





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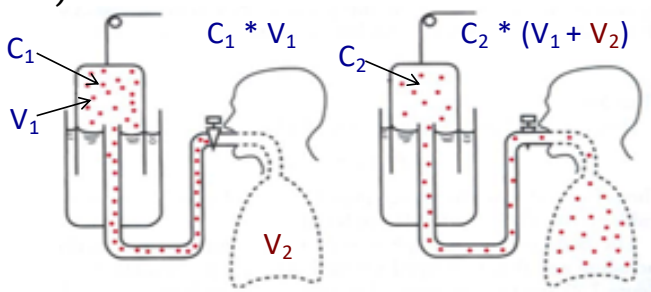
Measuring FRC: 2 tricks

- $c_1 \times V_1 = c_2 \times V_2$ (= amount)
  - He dilution
    - breathing from & into a bag w/ known initial [He]



  - N_2 washout
    - inhaling from an O_2 storage, exhaling into empty bag
  - after normal exhalation – FRC
  - after max exhalation - RV

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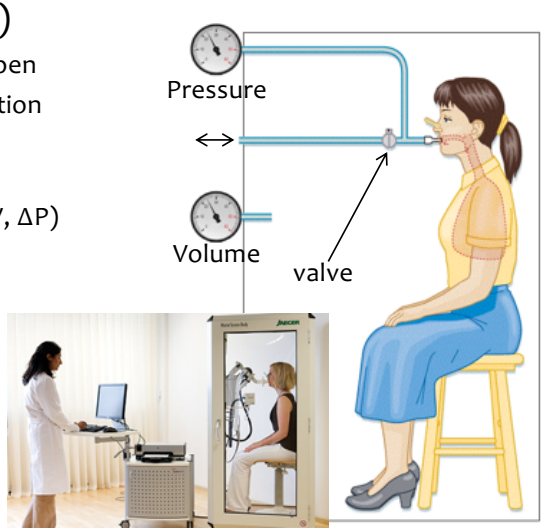
Measuring FRC - plethysmograph

- $P_1 \times V_1 = P_2 \times V_2$ (Boyle's law)
  - breathing from outside w/ valve open
  - P_1 & V_1 at the end of resting expiration (V_1 = FRC)
  - valve closed
  - small attempt at inspiration ($\rightarrow \Delta V, \Delta P$)
  - P_2 & V_2 ($P_1 - \Delta P$; $V_1 + \Delta V$)
  - $P_1 \times FRC = (P_1 - \Delta P) \times (V_1 + \Delta V)$
  - $FRC = \Delta V \times ((P_1 - \Delta P)/\Delta P)$



  - after max. expiration: RV

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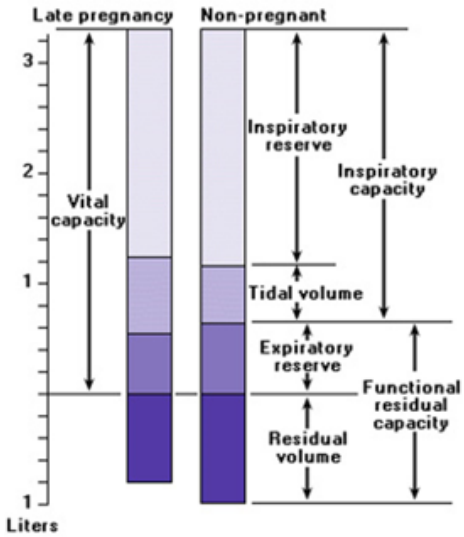
↓ FRC in pregnancy



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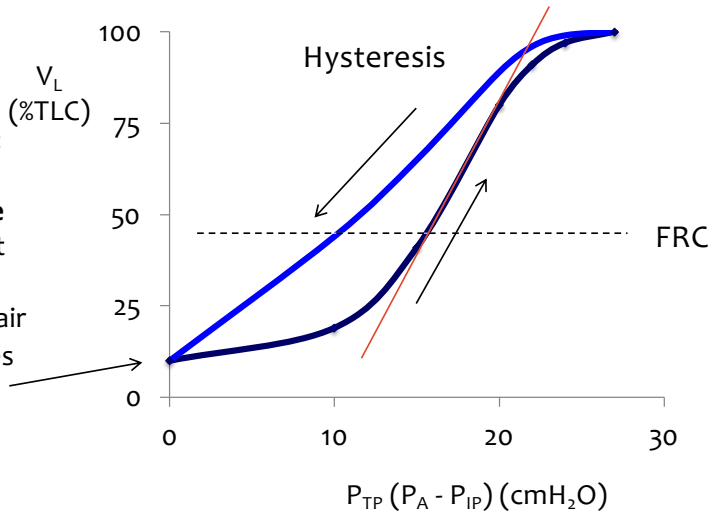
Static compliance

not included:
- **airway resistance**
- lung-chest friction
- inertia of air and tissues



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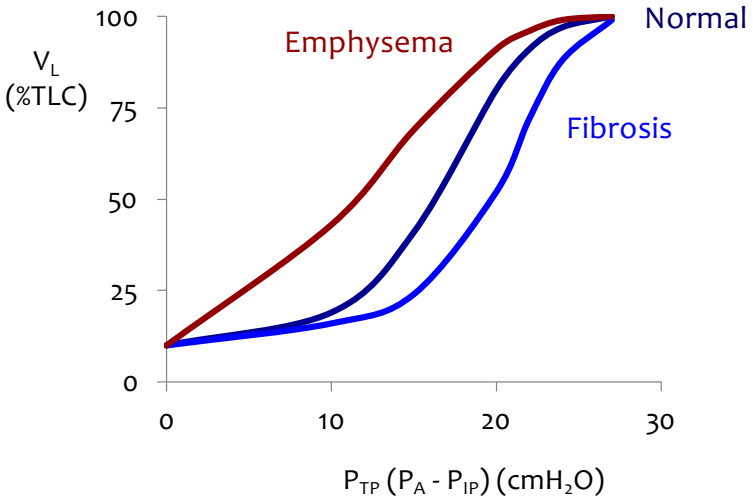
Static compliance



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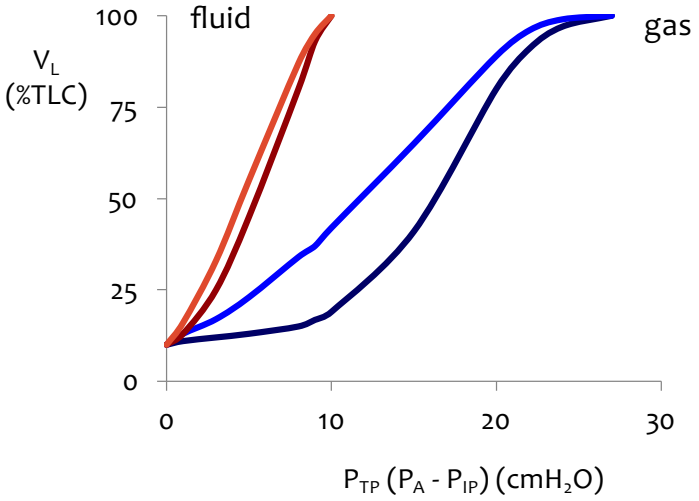
Static compliance & surface tension



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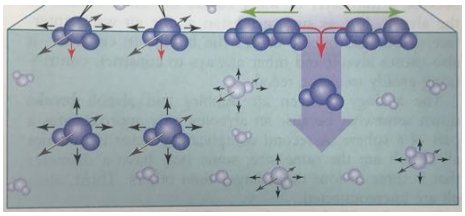
Surface tension

- inside water volume: molecules act on each other equally in all directions – cancels out
- on surface: only from below & laterally – pulling in → lateral pull
- on bubble surface like a strait-jacket – increases pressure inside, preventing further ↓r



- LaPlace law: $P = 2T/r$
- → smaller bubble empties into larger ($T_1/r_1 = T_2/r_2$)

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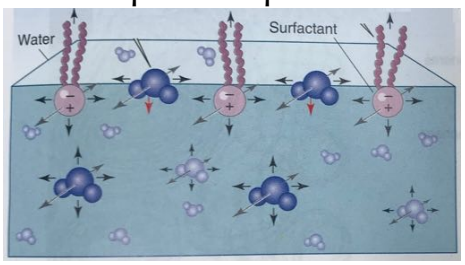
Surfactant: Type II. alveolal cells

- amphiphilic - hydrophobic & hydrophilic groups
- hydrophobic group extends out of water phase – pulls molecule out
- proteins ~10%
  - plasmatic proteins (1/2)
  - apolipoproteins (surfactant proteins SP-A, SP-B, SP-C, SP-D)



- 85% of lipids are phosphatidylcholins
  - mostly dipalmitoylphosphatidylcholin (DPPC)
  - phosphatidylglycerol - 11% of lipids

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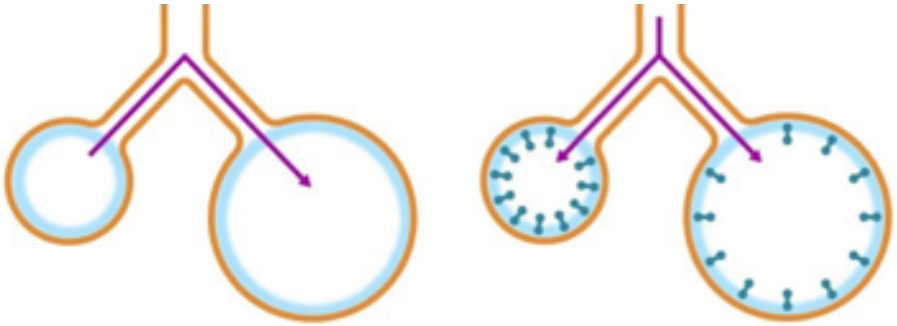
Surfactant prevents alveolar collapse

$P = 2T/r \rightarrow T_1/r_1 = T_2/r_2$

no surfactant

with surfactant



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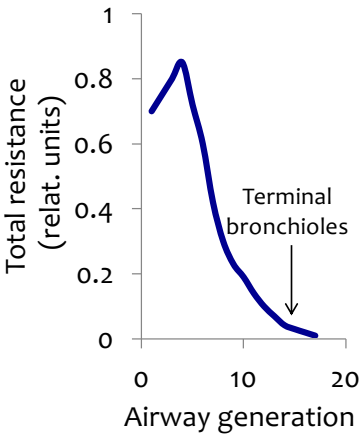
Airway resistance

- $\dot{V} = (P_A - P_B)/R$
- $R = (8/\pi) \times (\nu \times l)/r^4$ (Hagen-Poiseulle)
- $R = (P_A - P_B)/\dot{V}$
  = airway resistance
  (+20% is tissue resistance
  - friction of lungs & thoracic tissue at their movement against each other)



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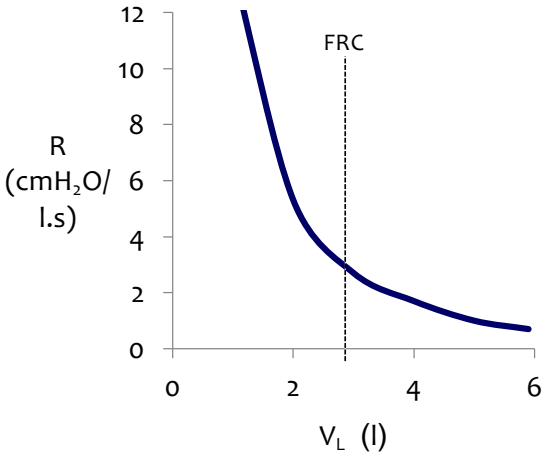
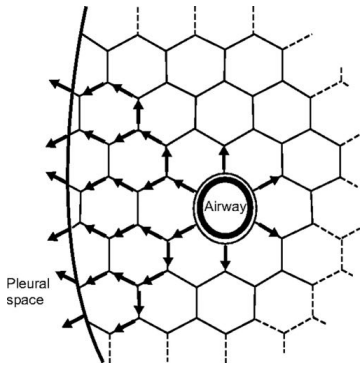
Airway resistance depends on lung volume





↑ airway r at ↑ V_L
(tissue tethering)

↑ R at expiration
(bronchiolar collapse)

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Regulation of airway resistance

- n. vagus – bronchoconstriction
- sympathicus – β_2 dilatation (NA weak agonist, adrenaline strong agonist)
- histamine - bronchoconstriction

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