Breathing:
Ventilation
Gas exchange in the lungs

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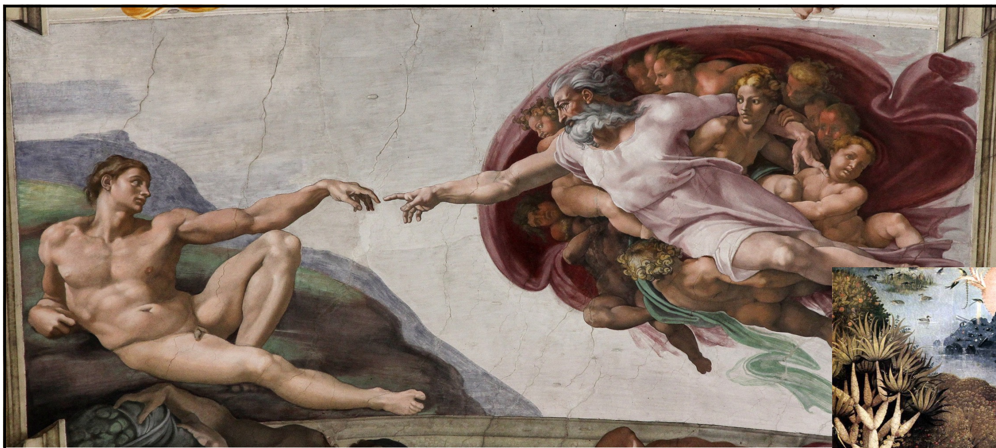


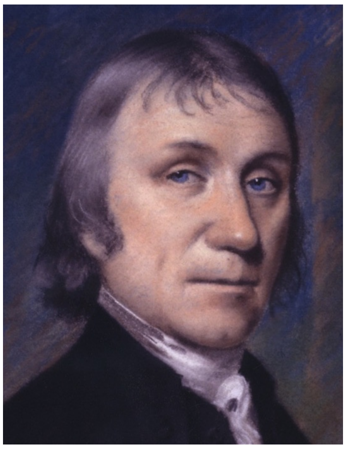
And the Lord God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul. (Genesis 2, 7)

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

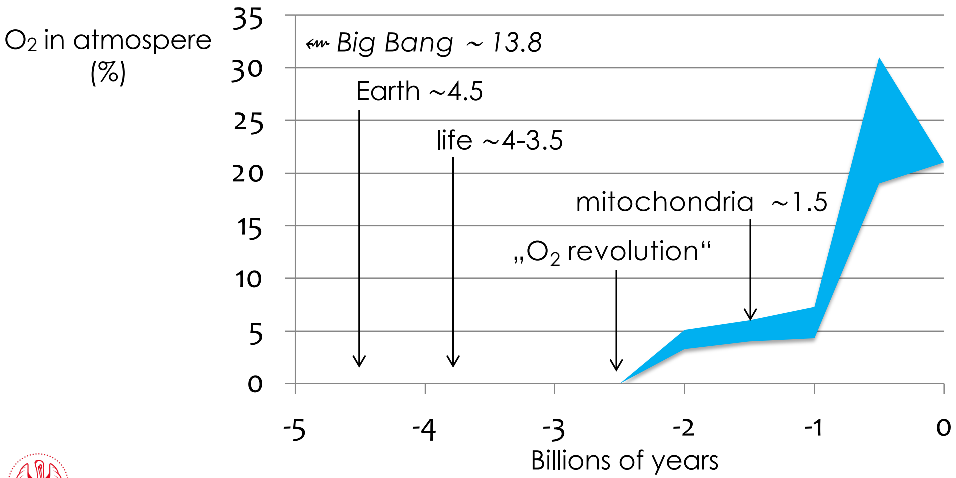
Oxygen

Joseph Priestley 1774

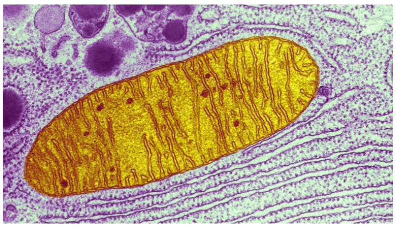
Antoine Laurent Lavoisier (?)



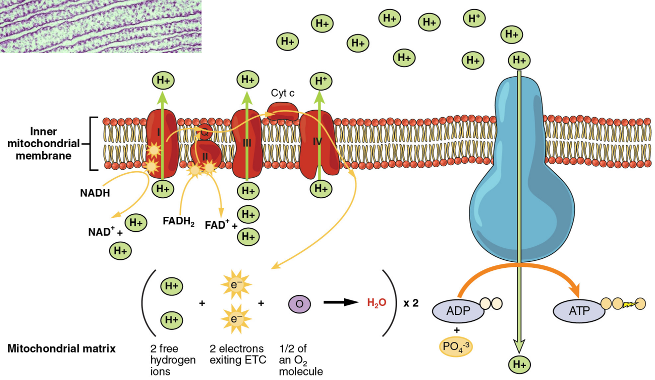
O_2 in atmosphere only recently



Mitochondria



endosymbiosis -1.5 bil years

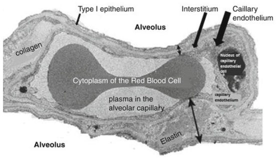


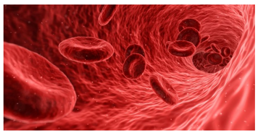
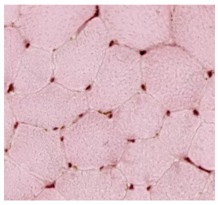
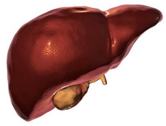
O_2 (& CO_2) transport

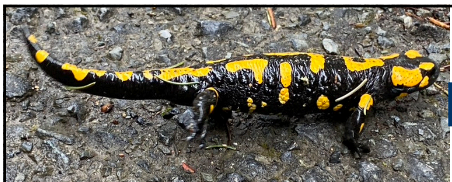
- small organisms – **diffusion**
  - short diffuse distance
  - large surface area relative to volume
- larger organisms - diffusion + **conduction**
- conduction in aquatic organisms: bringing water to the diffusive surface (O_2 in water << in air)
- conduction in terrestrial vertebrates:
  - breathing
  - circulation

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

convection ⇄ diffusion ⇄ convection ⇄ diffusion

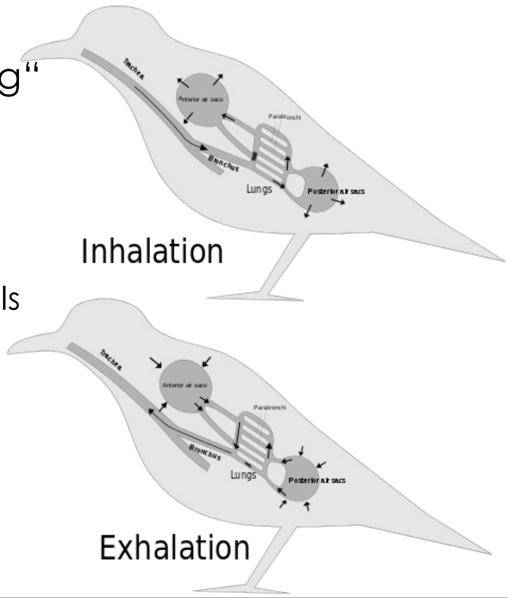





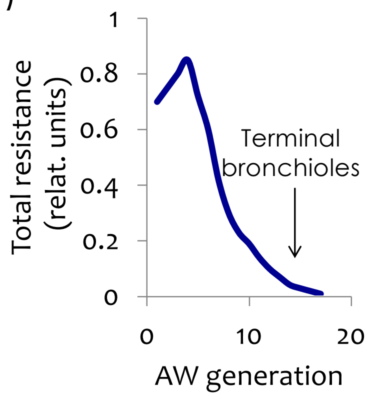
Breathing in vertebrates

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



Breathing in mammals

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



Determinants of lung gas transport

- Pulmonary ventilation
  - how O_2 and CO_2 reach the alveolocapillary membrane
  - what determines the amount of gas that is exchanged between the atmosphere and the alveoli
    - **dead space**
    - **functional residual capacity (FRC)**
- Pulmonary diffusion
  - determines the passage of O_2 and CO_2 across the alveolocapillary membrane
- Pulmonary perfusion
  - how venous blood is led into lungs form periphery
  - how O_2-rich blood with little CO_2 is led from lungs to periphery
- Lung ventilation/perfusion ratio

Lung ventilation

- exchange of gases between alveolar membrane & external atmosphere
- warming
- maximal saturation with water vapor
  - P_{H2O} at 36°C is 42 torr
- includes parts of the lungs where blood oxygenation (and CO_2 removal) does not take place

Resting lung position (end-expiration) = FRC = RV+ERV

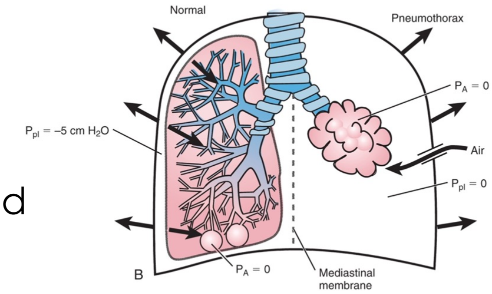
lung „elastic recoil“

x

chest tendency to expand

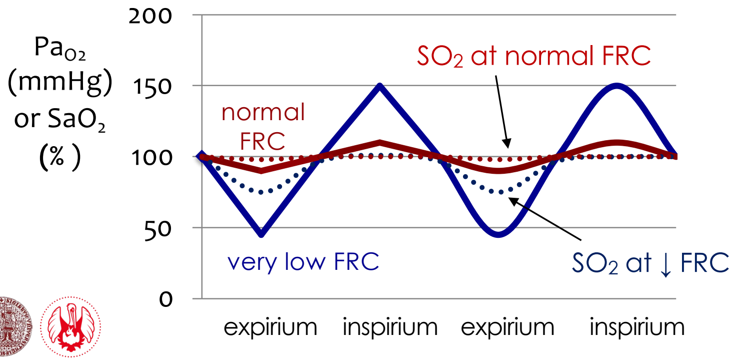
⇓

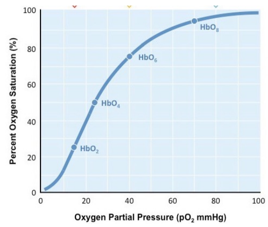
FRC ~2 l (vs. 0.5 l V_T)



Why FRC/RV?

- prevents collapse of airways & alveoli (→ compliance)
- buffers Pa_{O2} extremes during breathing cycle (perfusion is steady → relatively stable Pa_{O2})

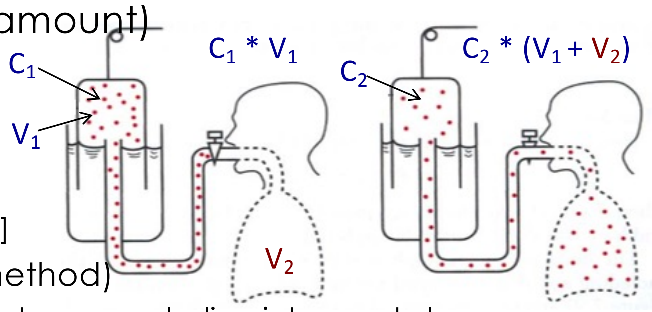




That is why we hyperventilate by increasing inspiration

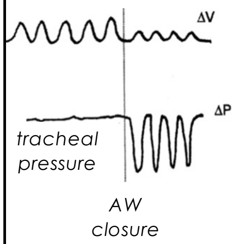
Measuring FRC: 2 tricks

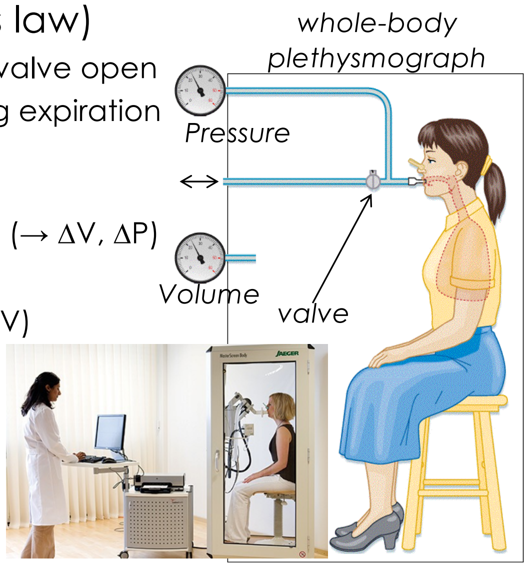
- $C_1 \times V_1 = C_2 \times V_2$ (= amount)
  - <u>He dilution</u> (closed method)
    - breathing from & into a bag w/ known initial [He]
  - <u>N_2 washout</u> (open method)
    - inhaling from an O_2 storage, exhaling into empty bag
    - N_2 amount: $C_i \times FRC = C_S \times V_S$ (C_i = initial, C_S & V_S = in spirometer)
  - after normal exhalation – FRC
  - after max exhalation - RV



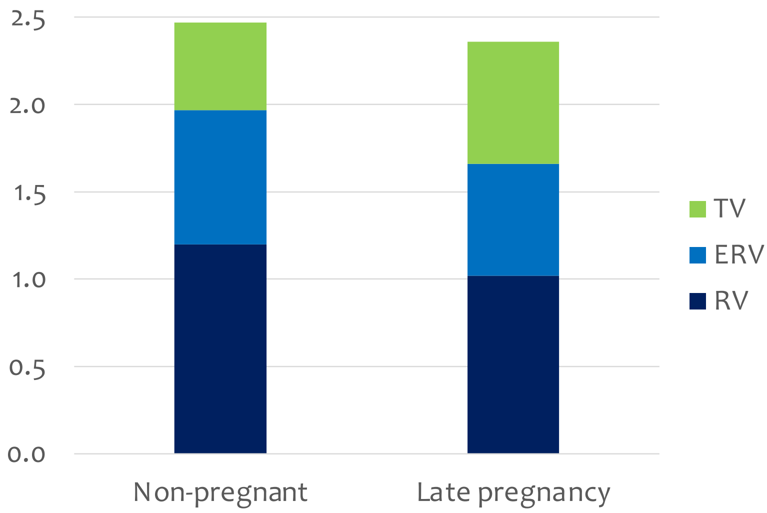
Measuring FRC - plethysmograph

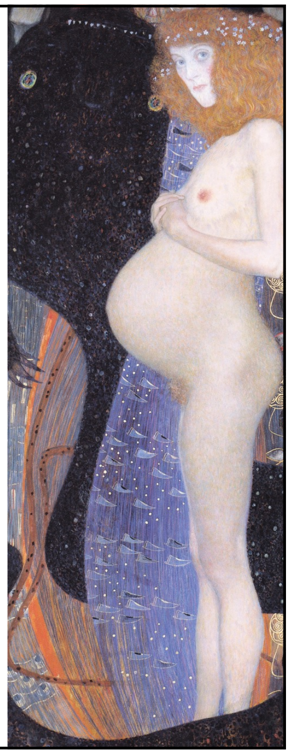
- $P_1 \times V_1 = P_2 \times V_2$ (Boyle's law)
  - breathing from outside w/ valve open
  - P_1 & V_1 at the end of resting expiration (V_1 = FRC)
  - valve closed
  - small attempt at inspiration (→ ΔV, ΔP)
  - P_2 & V_2 ($P_1 - \Delta P$; $V_1 + \Delta V$)
  - $P_1 \times FRC = (P_1 - \Delta P)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



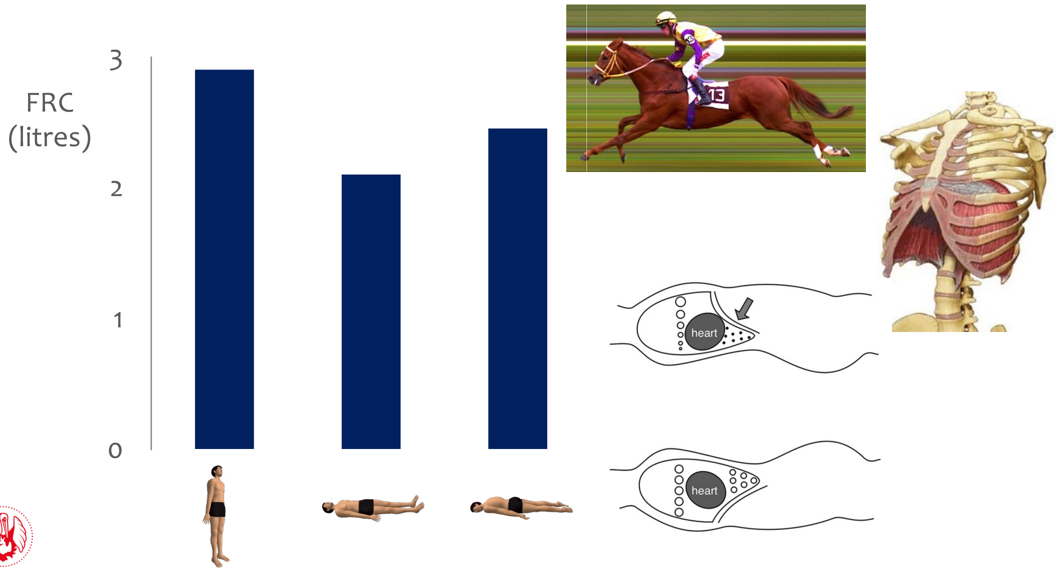


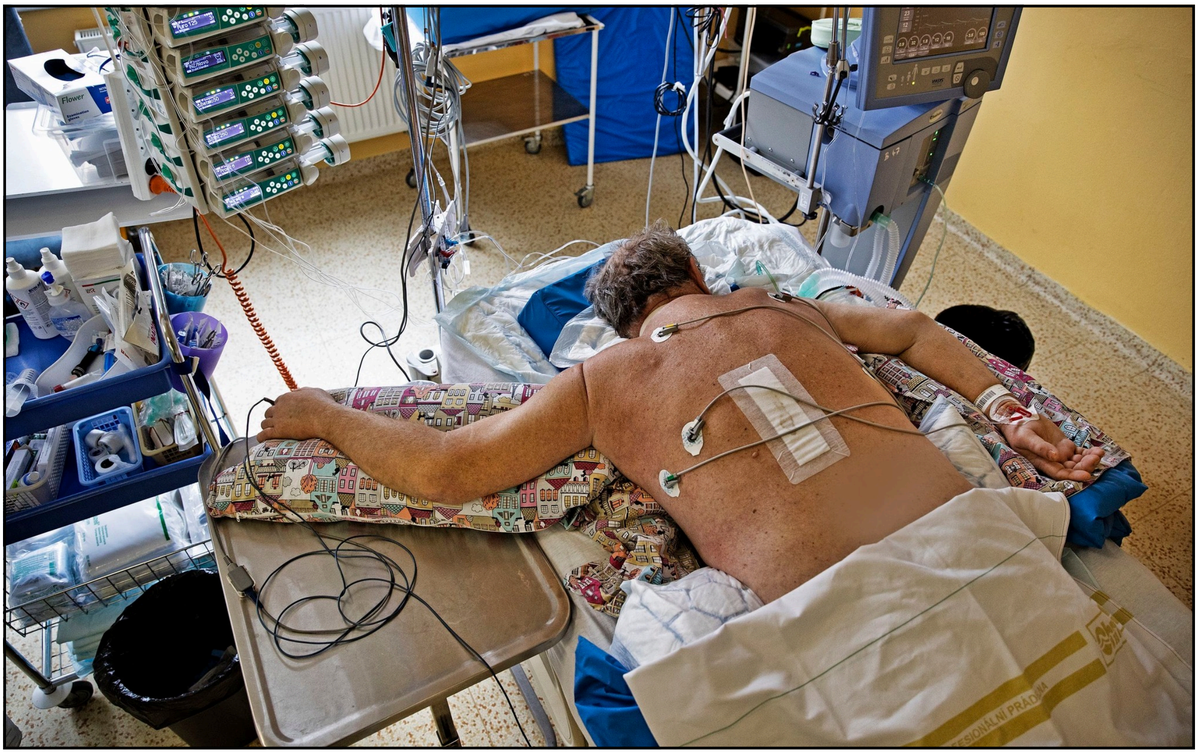
FRC↓ in pregnancy



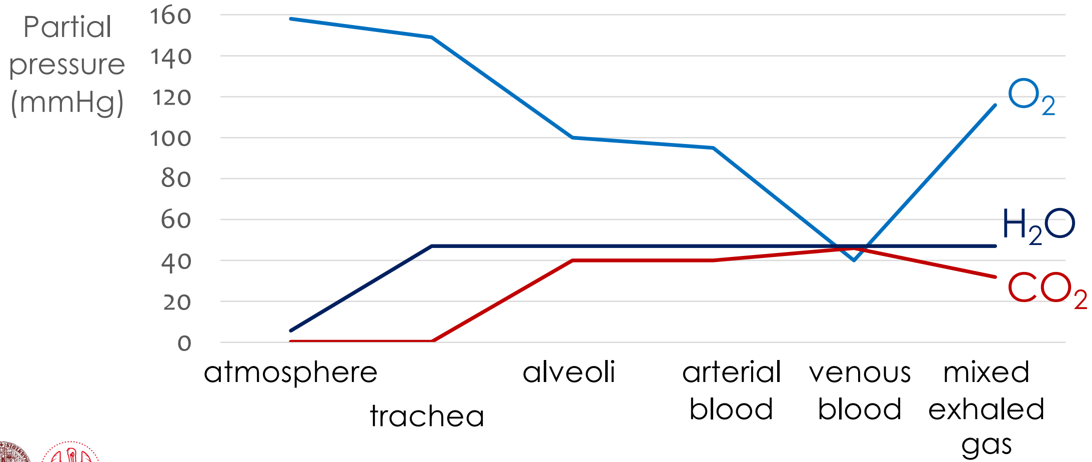


FRC depends on body posture



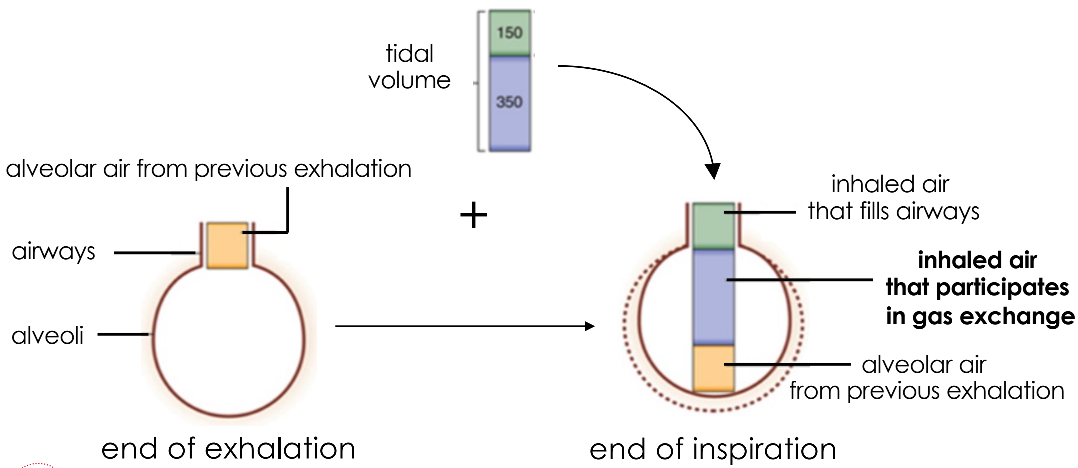


Partial pressures in separate parts of respiratory system



fluctuations during respiratory cycle are small - FRC

Dead space



Dead space

- $\dot{V}_T = V/t = V_T \, . \, f$
- V_T ~500 ml
- conducting airways ~150 ml (anatomical dead space)
  - on inspiration
    - V_D contains alveolar air from previous exhalation
    - last portion of inhalation does not get to alveoli
- $\dot{V}_A = (V_T - V_D) \, . \, f$
- $\dot{V}_D \sim 30\% \, \dot{V}_T$

Dead space (V_D)

- **volume, which is**
  - **<u>ventilated,</u>**
  - **but <u>does not participate in gas exchange</u>**

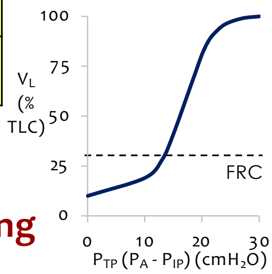
  - anatomical
  - functional

Ventilation of anatomical dead space ($\dot{V}_D$)

- Part of minute ventilation ($\dot{V} = V_T .f$) ventilates only the dead space where there is no gas exchange
  - $\dot{V}_D = V_D \times f$
- Large V_D limits alveolar ventilation $\dot{V}_A$ while maintaining $\dot{V}$
  - $\dot{V}_E = \dot{V}_D + \dot{V}_A$

Relationship between tidal volume, frequency & effective ventilation

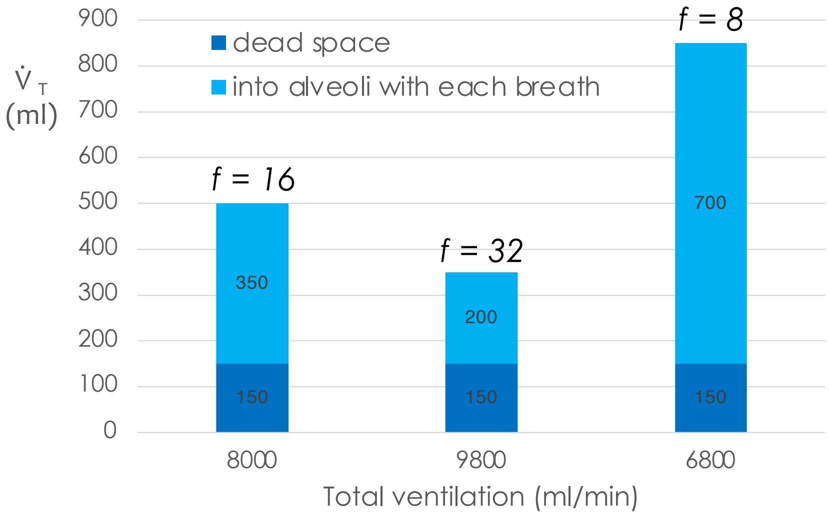
Minute ventilation ml/min	Tidal volume ml	**Frequency c/s**	Alveolar ventilation ml/min	Dead space ventilation ml/min	Effective ventil. %
8000	500	**16**			



Why not to breathe with minimal frequency?

Work of breathing

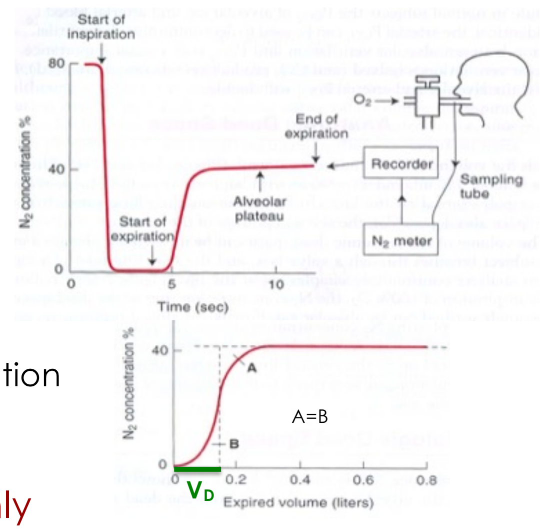
Effective ventilation calculator



effective ventilation 5.6 l/min in all cases

Measuring V_D volume: Fowler

- single-breath N_2 washout
  - 100% O_2 (0% N_2) inhaled
  - on exhalation, first 0% N_2 from V_D, then mixture
- exhaled [CO_2]
  - virtually 0% CO_2 at inspiration



anatomical V_D only

Measuring V_D: Bohr

mixed exhaled CO_2 (P_{ECO2})
= CO_2 from V_D + CO_2 from V_A

→ the higher V_D the more CO_2 from V_D (~0) "dilutes" CO_2 from V_A

$V_D/V_T = (P_{ACO2}-P_{ECO2}) / P_{ACO2}$ (Bohr equation)

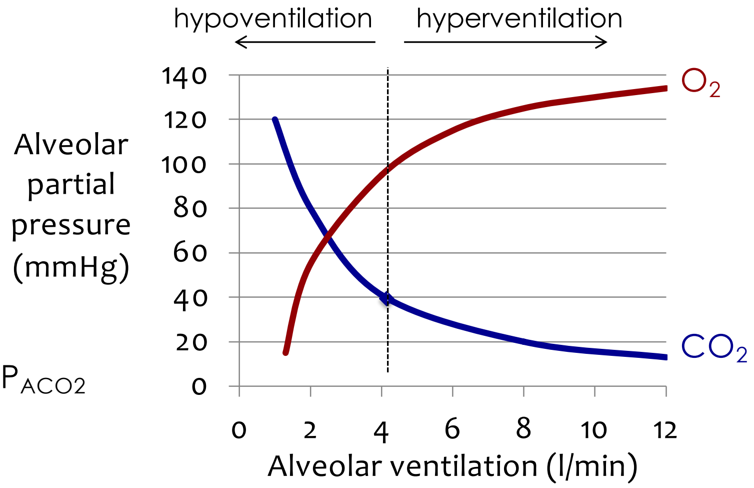
P_{ACO2} – end-expiratory (or P_{aCO2})

Both anatomical & alveolar V_D

Alveolar ventilation must get rid of all CO_2 produced in the body

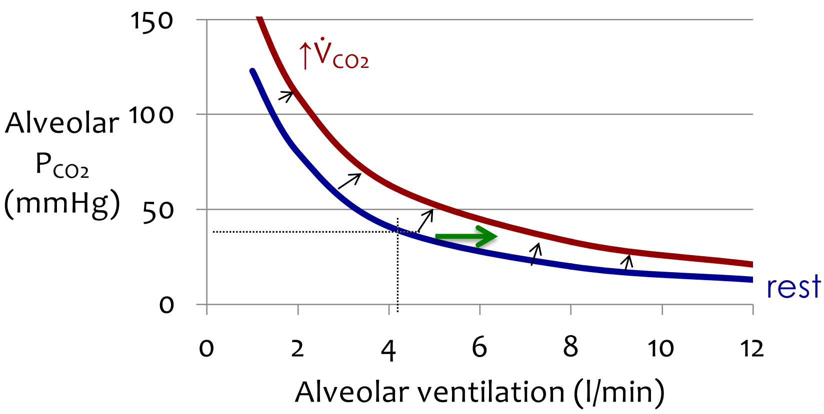
- at rest $\dot{V}_{CO2}$ ~ 200 ml/min
- $\dot{V}_A$ ~ 4200 ml/min (350 x 12)
  ⇓
- 200 ml CO_2 in 4200 ml of alveolar air → ~5%
- $\mathbf{\dot{V}_A = (K * \dot{V}_{CO2}) / P_{ACO2}}$ (K = 0.863) (alveolar ventilation equation)
- can be used to measure $\dot{V}_A$ (P_{ACO2} ~ P_{aCO2})

Alveolar P_{CO2} inversely proportional to $\dot{V}_A$ (respiratory hyperbole)



usually $P_{aCO2} \simeq P_{ACO2}$

To maintain P_{ACO2} with $\uparrow\dot{V}_{CO2}$ $\rightarrow \dot{V}_A$ must $\uparrow$



Measuring D_L

- CO instead of O_2
- similar D_L to O_2
- $P_{vCO} = 0$

Měření D_L

- CO místo O_2
- D_L podobná O_2 (koeficient)
- $P_{vCO} = O$
- $D_{LCO} = \dot{V}_{CO} / (P_{ACO} - P_{vCO})$
- úbytek CO z alveolárního vzduch během zadržení dechu