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Respiration Module

Session 2 – Lung ventilation

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The Lungs

- are a means of getting
- air to one side
- and blood to the other side
- of a thin membrane of large surface area

Exchange between air and blood

- occurs across the alveolar membrane
- ‘alveolar air’ has a different composition to the atmosphere
  - less Oxygen
  - more Carbon Dioxide
- exchange occurs by diffusion

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Alveolar air

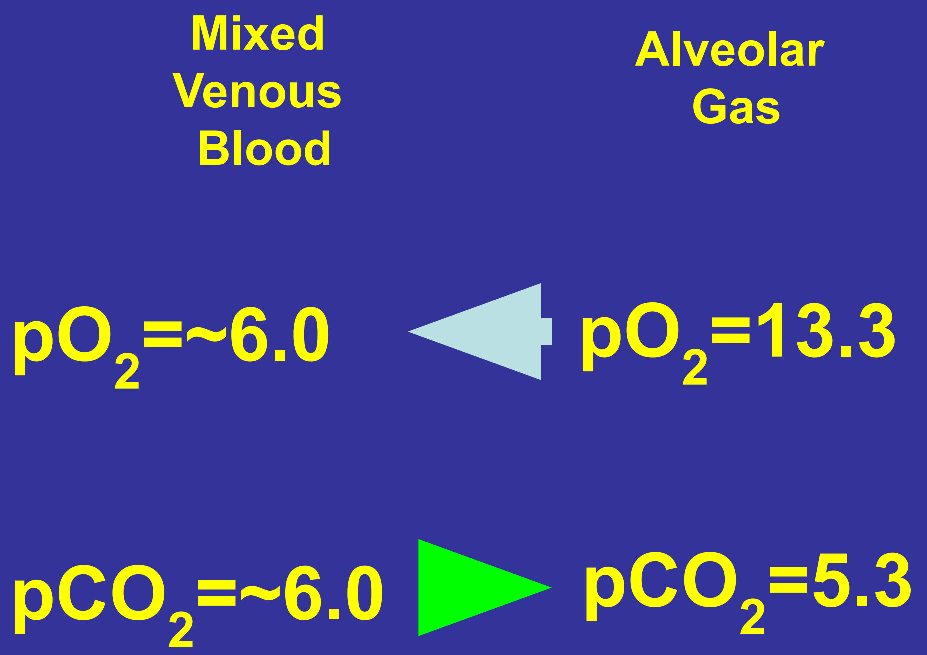
- pO_2 normally 13.3 kPa
- pCO_2 normally 5.3 kPa

Mixed venous blood

- returns to the lungs from the body
- pO_2 typically 6.0 kPa
- pCO_2 typically 6.5 kPa
- but varies with metabolism

Gradients of partial pressure

- pO_2 in alveolar gas > pO_2 in returning blood
- pCO_2 in alveolar gas < pCO_2 in returning blood
- so oxygen will diffuse into blood and carbon dioxide out



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Diffusion

- depends on
- area - large
- gradients - large
- diffusion resistance

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Diffusion resistance

- depends on
- nature of barrier
- nature of gas

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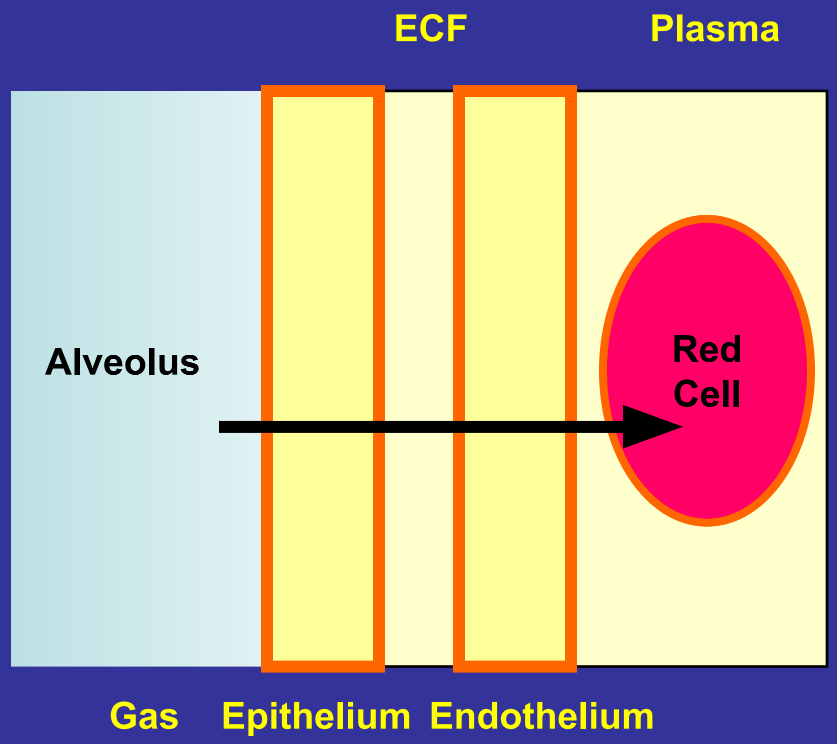
Diffusion barrier

- diffusion through gas to alveolar wall
- epithelial cell of alveolus
- tissue fluid
- endothelial cell of capillary
- plasma
- red cell membrane

Diffusion barrier

- gas diffusion to alveolar wall
- 5 cell membranes
- 3 layers of cytoplasm
- 2 layers of tissue fluid



Diffusion of gases

- gases diffuse through gases
- at rate inversely proportional to molecular weight
- big molecules diffuse slower
- carbon dioxide slower than oxygen

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Diffusion of gases

- gases diffuse through liquids
- at rate proportional to solubility
- CO_2 much more soluble than O_2
- so diffuses 21 times faster

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Diffusion barrier

- CO_2 diffuses much faster then O_2 overall
- so exchange of oxygen always limiting

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Overall diffusion resistance

- barrier 0.6μ thick
- oxygen exchange complete within 0.5 s of blood cell arriving in capillary
- blood cells spend about 1s in capillary
- so plenty of leeway
- gas diffusion not limiting on the lung

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Alveolar air

- in the normal lung
- blood leaving the alveolar capillaries
- is in equilibrium with alveolar air
- so has same pO_2 and pCO_2

Alveolar ventilation

- composition of alveolar air determines
- gas composition of arterial blood
- and therefore oxygen supply to tissues

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Alveolar ventilation

- exchange between alveolar gas
- and mixed venous blood
- will tend to lower pO_2 and raise pCO_2
- this is prevented by diffusion of oxygen into and carbon dioxide out of alveolar air
- from atmospheric air brought next to the alveoli by *ventilation*

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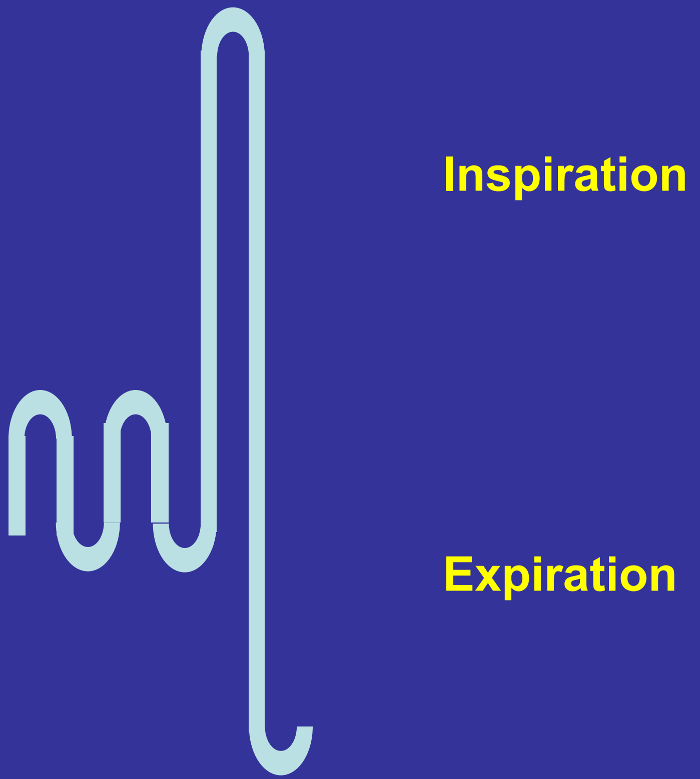
Ventilation

- expansion of lungs
- increases volume of
  - respiratory bronchioles
  - alveolar ducts
- so air flows down airways to them

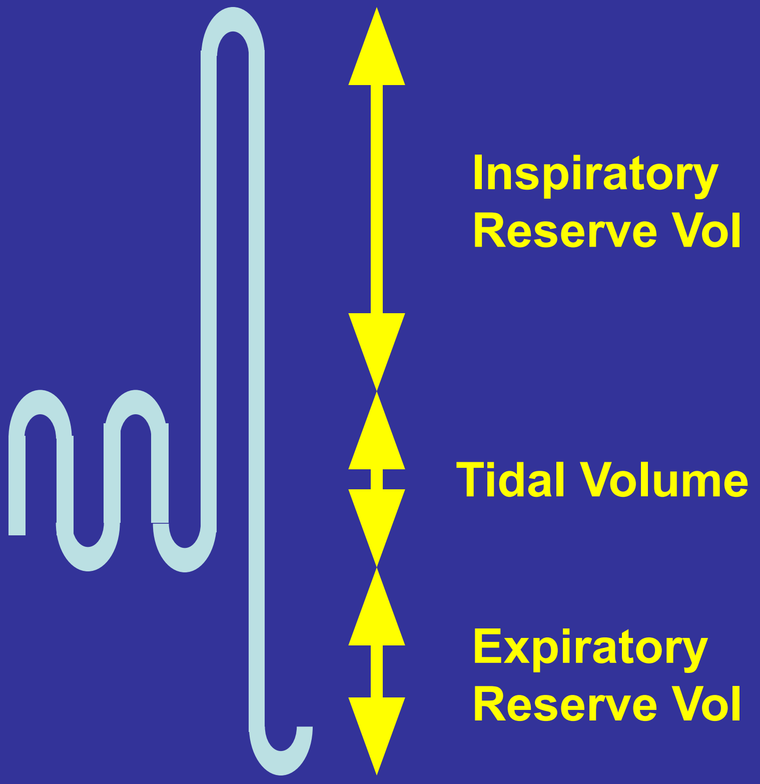
Measurement of ventilation

- use a spirometer
- subject breathes from a closed chamber over water
- whose volume changes with ventilation



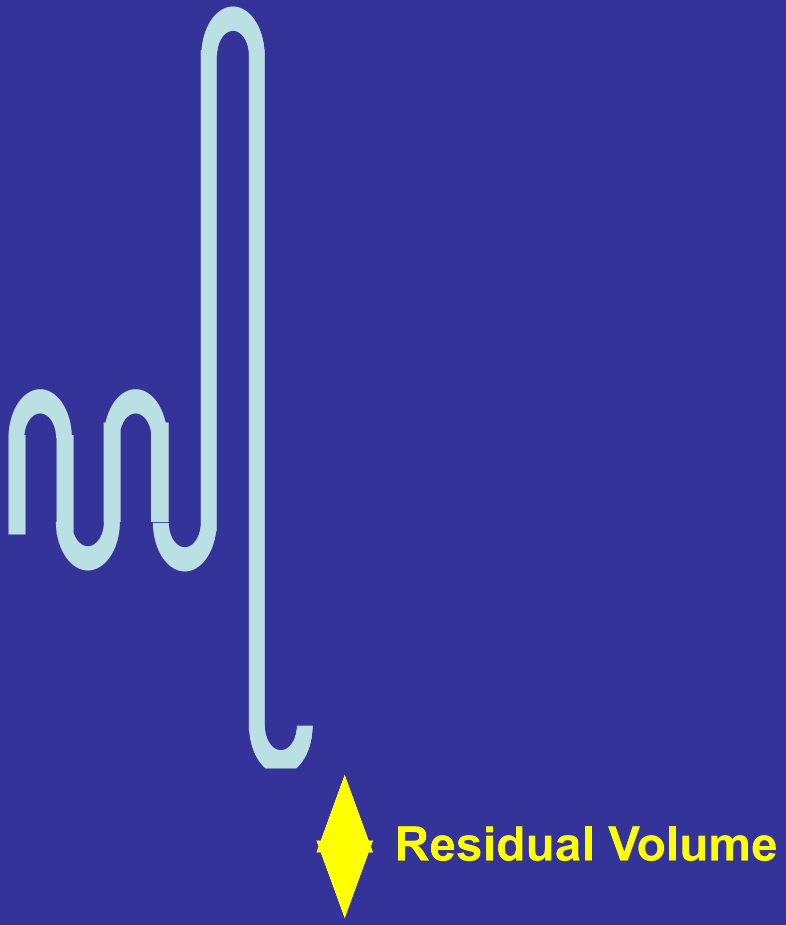
Lung volumes

- tidal volume
  - volume in and out with each breath
- inspiratory reserve volume
  - extra volume that can be breathed in over that at rest
- expiratory reserve volume
  - extra volume that can be breathed out over that at rest



Residual volume

- volume left in lungs at maximal expiration
- cannot be measured by spirometer
- use helium dilution



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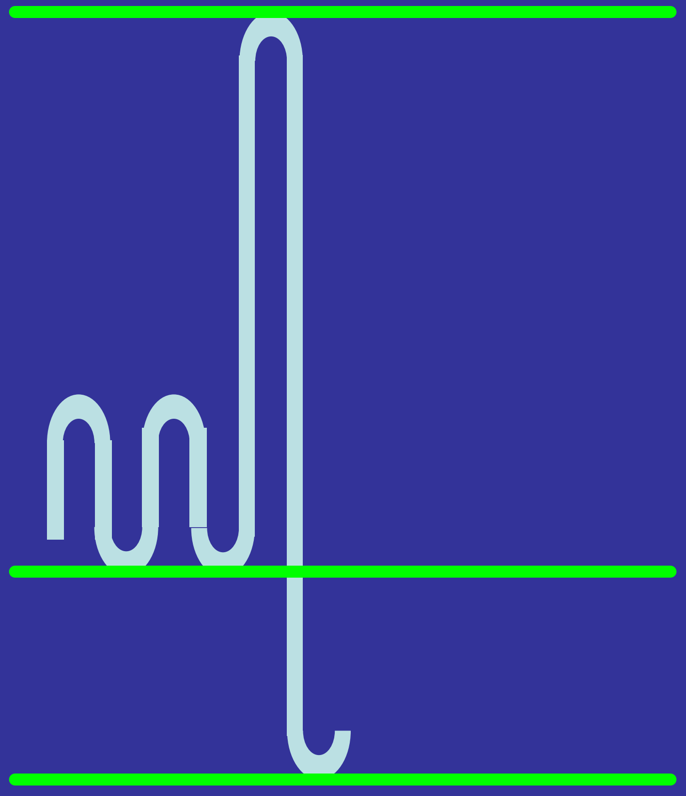
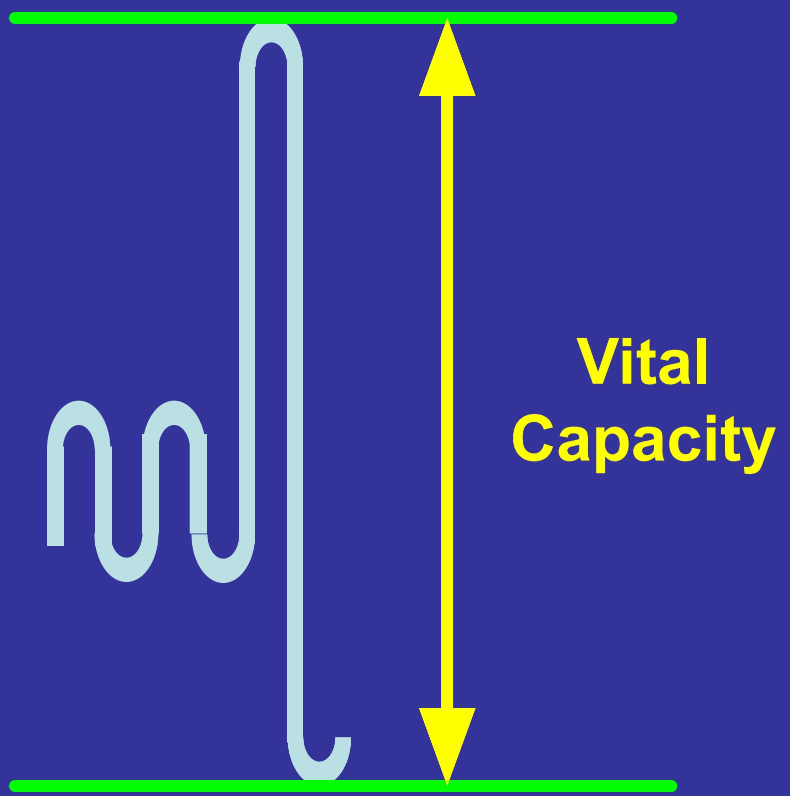
Lung Capacities

- lung volumes change with breathing pattern
- capacities do not
- because measured from fixed points in breathing cycle



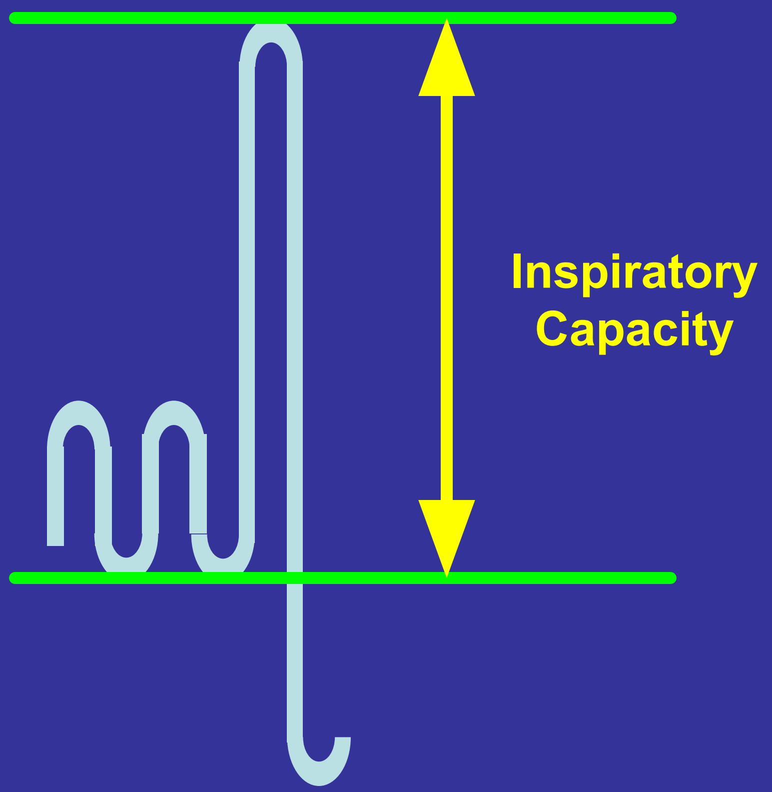
Vital Capacity

- measured from max inspiration to max expiration
- biggest breath that can be taken
- often changes in disease
- about 5l in typical adult



Inspiratory capacity

- biggest breath that can be taken
- from *resting expiratory level*
- which is lung volume at end of quiet expiration
- inspiratory capacity typically 3l



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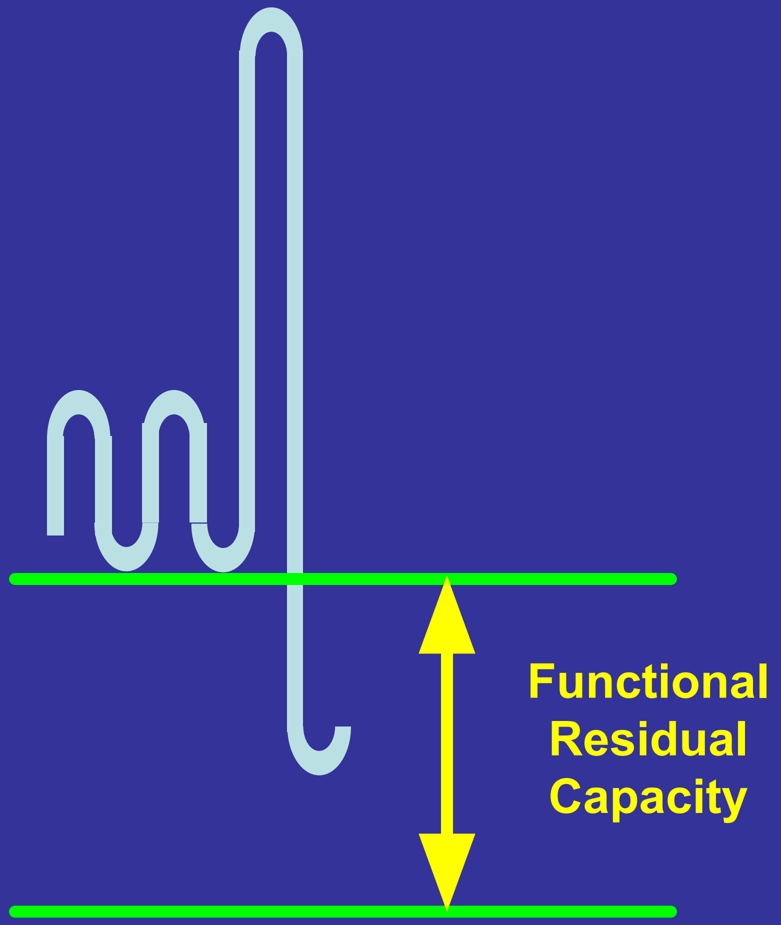
Functional residual capacity

- volume of air in lungs
- at resting expiratory level
- typically 2l
- (expiratory reserve volume + residual volume)



Typical values

- Tidal Volume - 0.5l
- Inspiratory reserve - 2.5l
- Expiratory reserve - 1.5l
- Residual volume - 0.8l
- Functional residual capacity - 2.3l
- Inspiratory capacity - 3.0l
- Vital Capacity - 5.0l
- Total lung capacity - 5.8l

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Ventilation rate

- the amount of air moved into and out of a space per minute
- product of volume moved per breath
- and respiratory rate

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Pulmonary Ventilation rate

- Tidal volume x respiratory rate
- typically 8l.min^{-1} at rest
- can exceed 80 l.min^{-1} in exercise

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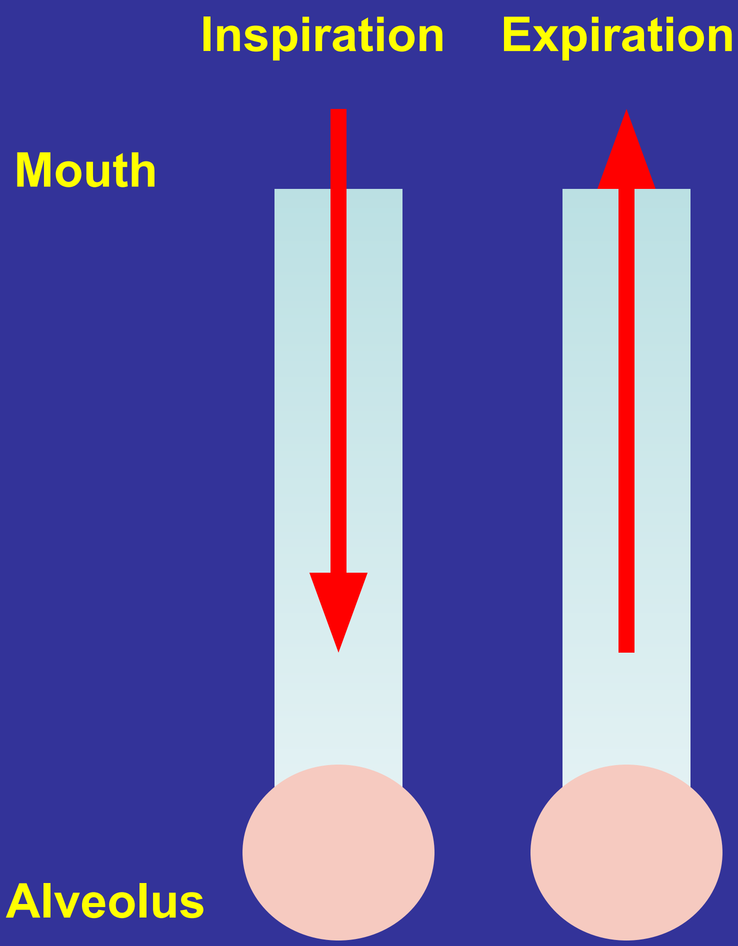
Dead space

- air enters and leaves lungs by same airways
- last air in stays in airways
- and is first air out
- so it does not reach the alveoli
- and is ‘wasted’



Alveolar ventilation rate

- the amount of air that actually reaches the alveoli
- to calculate need to allow for ‘wasted’ ventilation of dead spaces

Serial dead space

- the volume of the airways
- used to be known as ‘anatomical dead space’
- measured by nitrogen washout
  - see later lecture
- typically about 0.15l

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Distributive dead space

- some parts of the lung are not airways, but do not support gas exchange
  - dead or damaged alveoli
  - alveoli with poor perfusion
- add to serial dead space
- total is ‘physiological dead space’
- typically 0.17l

Calculation of alveolar ventilation rate

- dead space must be completely filled with air at each breath
- dead space ventilation rate therefore
- dead space vol x resp rate
- subtract this from pulmonary ventilation rate to get AVR

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Example

- PVR = TV x RR
  - 0.5l x 16 = 8l.min^{-1}
- DSVR = DSV x RR
  - 0.15l x 16 = 2.4l.min^{-1}
- AVR = PVR - DSVR
  - 8 - 2.4 = 5.6 l.min^{-1}

Pattern of breathing

- with TV of 0.5l and RR of 16
- about one third of inspired air is ‘wasted’

Rapid shallow breathing

- if TV=0.25l & RR=32
- PVR = TV x RR
  - $0.25l \times 32 = 8l.min^{-1}$
- DSVR = DSV x RR
  - $0.15l \times 32 = 4.8l.min^{-1}$
- AVR = PVR - DSVR
  - $8 - 4.8 = 3.2\ l.min^{-1}$
- almost two thirds ‘wasted’

Slow deep breathing

- if TV=1l & RR=8
- PVR = TV x RR
  - 1l x 8 = $8l.min^{-1}$
- DSVR = DSV x RR
  - 0.15l x 8 = $1.2l.min^{-1}$
- AVR = PVR - DSVR
  - 8 - 1.2 = $6.8l.min^{-1}$
- much less wasted

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Pattern of breathing

- slow, deep breathing gets most air to alveoli
- but is hard work
- so at rest we adopt an intermediate rate and depth