What you will learn today

- Oxygen cascade
- PI\textsubscript{O}_2
- PA\textsubscript{O}_2
- Diffusion
- \Delta\text{AaPO}_2: Shunt
- Oxygen transport / content / delivery
- Pulse oximetry
- Therapeutic principles to improve oxygenation
- CO\subscript{2}-transport
- Capnography
Critical dependency on oxygen

Principal stores of body oxygen

<table>
<thead>
<tr>
<th></th>
<th>Breathing air (ml)</th>
<th>Breathing 100% O₂ (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the lungs (FRC)</td>
<td>450</td>
<td>3000</td>
</tr>
<tr>
<td>In the blood</td>
<td>850</td>
<td>950</td>
</tr>
<tr>
<td>Dissolved in tissue fluids</td>
<td>50</td>
<td>?100</td>
</tr>
<tr>
<td>Myoglobin</td>
<td>?200</td>
<td>?200</td>
</tr>
<tr>
<td>Total</td>
<td>1550</td>
<td>4250</td>
</tr>
</tbody>
</table>

Oxygen consumption = 3-4 ml/kg/min = 300 ml/min

Tolerance to hypoxia of various tissues

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Survival time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>&lt; 3 min</td>
</tr>
<tr>
<td>Kidney and liver</td>
<td>15-20 min</td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>60-90 min</td>
</tr>
<tr>
<td>Vascular smooth muscle</td>
<td>24-72 h</td>
</tr>
<tr>
<td>Hair and nails</td>
<td>Several days</td>
</tr>
</tbody>
</table>

Oxygen cascade
Oxygen cascade:
Decrease of $PO_2$ from air to mitochondria

Pressure of inspired oxygen ($PiO_2$)

Dalton’s law:

\[ b \times \text{atm} = b \times \frac{\text{atm}}{0} \]

$PiO_2 = 0.2094 \times 760 = 159 \text{mmHg}$ (0°C, dry)

$PiO_2 = 1.0 \times 760 = 760 \text{mmHg}$

STPD = Standard Temperature Pressure Dry
Pressure of inspired oxygen ($\text{PiO}_2$)

**How to increase $\text{FiO}_2$**

- ~40%
- ~40-60%
- ~60-80%
- 100%

**Pressure of inspired oxygen ($\text{PiO}_2$)**

- Concentration of atmospheric oxygen: 20.94% (159 mmHg) (dry gas!)
- Humidification of gas during passage through the respiratory tract
- Dilution of oxygen by added water vapour

$$b!O^2 = b!O^3 (\text{H}_2\text{O}) * (b - b^{\text{H}_2\text{O}})$$

$$\text{PiO}_2 = 0.2094 * (760 - 47) = 149 \text{mmHg (37°C)}$$

*BTPS = Body Temperature Pressure Saturated*
Pressure of inspired oxygen (PiO₂)

- **Constant concentration of atmospheric oxygen:** 20.94% (159 mmHg)
- Decrease of barometric pressure with altitude

\[ \text{PiO}_2 = \text{FiO}_2 (\text{dry}) \times (P_B - P_{H_2O}) \]

### Table 17.1 Barometric pressure relative to altitude

<table>
<thead>
<tr>
<th>Altitude (feet)</th>
<th>Barometric pressure (kPa)</th>
<th>Inspired gas P\text{O}_2 (mmHg)</th>
<th>Equivalent P\text{O}_2 at sea level</th>
<th>Percentage oxygen required to give sea level value of inspired gas P\text{O}_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>10.9</td>
<td>149</td>
<td>20.9</td>
</tr>
<tr>
<td>2000</td>
<td>610</td>
<td>18.4</td>
<td>138</td>
<td>19.4</td>
</tr>
<tr>
<td>4000</td>
<td>1220</td>
<td>16.9</td>
<td>127</td>
<td>17.8</td>
</tr>
<tr>
<td>6000</td>
<td>1830</td>
<td>15.7</td>
<td>118</td>
<td>16.6</td>
</tr>
<tr>
<td>8000</td>
<td>2440</td>
<td>14.4</td>
<td>108</td>
<td>15.1</td>
</tr>
<tr>
<td>10000</td>
<td>3050</td>
<td>13.3</td>
<td>100</td>
<td>14.0</td>
</tr>
<tr>
<td>12000</td>
<td>3660</td>
<td>12.1</td>
<td>91</td>
<td>12.8</td>
</tr>
<tr>
<td>14000</td>
<td>4270</td>
<td>11.1</td>
<td>83</td>
<td>11.6</td>
</tr>
<tr>
<td>16000</td>
<td>4880</td>
<td>10.1</td>
<td>76</td>
<td>10.7</td>
</tr>
<tr>
<td>18000</td>
<td>5490</td>
<td>9.2</td>
<td>69</td>
<td>9.7</td>
</tr>
<tr>
<td>20000</td>
<td>6100</td>
<td>8.4</td>
<td>63</td>
<td>8.8</td>
</tr>
<tr>
<td>22000</td>
<td>6710</td>
<td>7.6</td>
<td>57</td>
<td>8.0</td>
</tr>
<tr>
<td>24000</td>
<td>7320</td>
<td>6.9</td>
<td>52</td>
<td>7.3</td>
</tr>
<tr>
<td>26000</td>
<td>7930</td>
<td>6.3</td>
<td>47</td>
<td>6.6</td>
</tr>
<tr>
<td>28000</td>
<td>8540</td>
<td>5.6</td>
<td>42</td>
<td>5.9</td>
</tr>
<tr>
<td>30000</td>
<td>9150</td>
<td>4.9</td>
<td>37</td>
<td>5.2</td>
</tr>
<tr>
<td>32000</td>
<td>9760</td>
<td>4.3</td>
<td>32</td>
<td>4.8</td>
</tr>
<tr>
<td>34000</td>
<td>10370</td>
<td>3.7</td>
<td>27</td>
<td>3.8</td>
</tr>
<tr>
<td>35000</td>
<td>10980</td>
<td>3.2</td>
<td>22</td>
<td>3.1</td>
</tr>
<tr>
<td>37000</td>
<td>11590</td>
<td>2.7</td>
<td>17</td>
<td>2.9</td>
</tr>
<tr>
<td>39000</td>
<td>12200</td>
<td>2.3</td>
<td>12</td>
<td>2.6</td>
</tr>
<tr>
<td>45000</td>
<td>13700</td>
<td>1.8</td>
<td>8</td>
<td>1.6</td>
</tr>
<tr>
<td>50000</td>
<td>15200</td>
<td>1.4</td>
<td>4</td>
<td>1.1</td>
</tr>
<tr>
<td>55000</td>
<td>16700</td>
<td>1.0</td>
<td>0</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Pressure of inspired oxygen (PiO₂)

Oxygen cascade at high altitude

Table 1: Arterial Blood Gas Measurements and Calculated Values for Pulmonary Gas Exchange from Four Subjects at an Altitude of 5400 m, During Descent from the Summit of Mount Everest.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subject No. 1</th>
<th>Subject No. 2</th>
<th>Subject No. 3</th>
<th>Subject No. 4</th>
<th>Group Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂ (mm Hg)</td>
<td>105.0</td>
<td>106.4</td>
<td>110.0</td>
<td>108.4</td>
<td>108.4</td>
</tr>
<tr>
<td>PaCO₂ (mm Hg)</td>
<td>42.2</td>
<td>45.2</td>
<td>40.2</td>
<td>40.0</td>
<td>42.0</td>
</tr>
<tr>
<td>Blood pH</td>
<td>7.36</td>
<td>7.39</td>
<td>7.37</td>
<td>7.38</td>
<td>7.37</td>
</tr>
<tr>
<td>Base excess of blood (mmol/L)</td>
<td>-13.2</td>
<td>-12.8</td>
<td>-14.1</td>
<td>-13.5</td>
<td>-13.3</td>
</tr>
<tr>
<td>Lactate concentration (mmol/L)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>SVO₂ (%)</td>
<td>48.1</td>
<td>44.4</td>
<td>43.7</td>
<td>48.7</td>
<td>46.0</td>
</tr>
<tr>
<td>Hemoglobin (g/dL)</td>
<td>15.2</td>
<td>18.7</td>
<td>18.5</td>
<td>19.4</td>
<td>18.7</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>0.81</td>
<td>0.74</td>
<td>0.72</td>
<td>0.70</td>
<td>0.72</td>
</tr>
<tr>
<td>PaO₂ — PaO₂ (mm Hg)</td>
<td>32.4</td>
<td>36.9</td>
<td>27.4</td>
<td>33.2</td>
<td>30.0</td>
</tr>
<tr>
<td>Arterio-venous oxygen difference (mm Hg)</td>
<td>2.89</td>
<td>7.85</td>
<td>6.44</td>
<td>4.51</td>
<td>5.41</td>
</tr>
</tbody>
</table>

Pressure of alveolar oxygen (PAO₂)

Alveolar air equation

\[ \text{PAO}_2 \approx \text{PiO}_2 - \text{PaCO}_2 \]

\[ \text{PAO}_2 \approx \text{PiO}_2 - \text{PaCO}_2 \times \text{RQ} \]

\[ \approx 149 - 40/0.9 \]
\[ \approx 105 \text{ mmHg} \]
\[ \approx 14\% \text{ (of 760mmHg)} \]

\[ \text{PAO}_2 = \text{PiO}_2 - \text{PaCO}_2 \left( \frac{\text{PiO}_2 - \text{PeO}_2}{\text{PeCO}_2} \right) \]

Hypoventilation: can cause hypoxia

Hyperventilation: compensatory response to high altitude

Diffusion
**Diffusion Barriers**

Gas space within the alveolus: uniform distribution of $O_2$, $N_2$, $CO_2$ → No barrier

Alveolar lining fluid: thin

Tissue barrier:
- Alveolar epithelium: 0.2µm
- Interstitial space: 0.1µm
- Endothelium: 0.2µm

Plasma layer

Diffusion into and within the red blood cells

Uptake of oxygen by hemoglobin
(time-dependent reaction)

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**Diffusion Fick’s law**

\[
\frac{\Delta n}{\Delta t} = -D \ast A \ast \frac{\Delta c}{\Delta \chi}
\]

$D =$ Diffusion coefficient

Wall thickness $\chi$

$P_{\text{cap}}O_2 \quad P_{A}O_2$
Diffusion
Pulmonary edema

Diffusion capacity:
Calculation

\[ DL_{CO} = 10.9 \times height(m) - 0.067 \times age(years) - 5.89 \]

30 years, 1.78m \( \rightarrow \) 34.4 ml/min/mmHg

\[ DL_{CO} = 7.1 \times height(m) - 0.054 \times age(years) - 0.89 \]

- Lung volume
- Posture (Supine > standing/sitting)
- Age
- Sex (Men > Women)
- White > Black Race
**Alveolar/arterial PO₂ difference**

\[ \text{PAO}_2 = 105 \text{ mmHg} \]

\[ \Delta \text{AaPO}_2 = 15-35 \text{ mmHg} \]

\[ \text{PaO}_2 = 102 – 0.33 \times \text{age} \] (mmHg)
Alveolar/arterial \( \text{PO}_2 \) difference

**SHUNT**

**Anatomical (extrapulmonary)**

- Thebesian veins (0.3% of CO)
- Bronchial veins (1% of CO)
- Congenital heart disease

**Intrapulmonary** \( \text{Va/Q} < 1 \)

- Atelectasis
- Pneumonia
- ALI
- Pulmonary collapse

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**Venous admixture**

**Shunt: Calculation**

\[
\dot{Q}_T = \dot{Q}_c + \dot{Q}_s \\
\dot{Q}_T \times CaO_2 = \dot{Q}_c \times CcO_2 + \dot{Q}_s \times C\bar{v}O_2 \\
\frac{\dot{Q}_s}{\dot{Q}_T} = \frac{CcO_2 - CaO_2}{CcO_2 - C\bar{v}O_2}
\]
Venous admixture

The iso-shunt diagram

With increasing shunt (≥ 30%), hypoxemia can no longer be treated with added inspired oxygen

Venous admixture

Summary

Changes in $P_{O_2}$ in the pulmonary capillary blood, arterial blood, and systemic capillary blood, demonstrating the effect of "venous admixture."
**Oxygen cascade**

**Oxygen transport within the blood:**

**Physically dissolved**

**Henry's law**

\[ c = \alpha \times p \]

- \( c \) = concentration
- \( \alpha \) = Bunsen solubility coefficient
- \( p \) = partial pressure

\[ \alpha = 0.000031 \text{ ml } O_2 / \text{ ml blood } / \text{ mmHg} \]

\[ \Rightarrow \text{PO}_2 \ 100 \text{ mmHg} \]

\[ 0.3 \text{ ml } O_2 / 100 \text{ ml} \]
Oxygen transport within the blood:
Chemically bound: Hemoglobin

Chemically bound: Hemoglobin

\[ \text{Hb} + 4\text{O}_2 \rightleftharpoons \text{HbO}_2 + 3\text{O}_2 \rightleftharpoons \text{Hb(O}_2)_3 + 2\text{O}_2 \]

\[ \text{K}_1, \text{K}_2, \text{K}_3, \text{K}_4 \]

\[ \begin{align*}
\text{Hb} & : 0.05 \\
\text{HbO}_2 & : 0.04 \\
\text{Hb(O}_2)_3 & : 0.45 \\
\text{Hb(O}_2)_4 & : 0.50 
\end{align*} \]
Oxygen transport within the blood: Oxyhemoglobin dissociation curve

**Sigmoidal shape:**
Binding of the 1st O₂ molecule increases affinity of hemoglobin for the next O₂ molecule.

**Advantages:**
1) Decreases in PO₂ are tolerated over a relatively wide range
2) Maximal saturation is achieved at "normal" PO₂
3) O₂-release is facilitated at low PO₂

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Oxygen transport within the blood: Position of the HbO₂ dissociation curve

**P₅₀**
PO₂ that achieves a SpO₂ of 50% (27mmHg)

**Right shift:**
↑PO₂ = > 27 mmHg
Less affinity of Hb for O₂
Facilitated O₂-release into periphery

**Left shift:**
↓PO₂ = < 27 mmHg
Higher affinity of Hb for O₂
Impaired O₂-release into periphery
Oxygen transport within the blood: Position of the HbO₂ dissociation curve

**Right shift:**
- pH
- pCO₂
- Temp.
- 2,3-DPG

**Left shift:**
- pH
- pCO₂
- Temp.
- 2,3-DPG

Oxygen transport within the blood: Bohr effect

Affinity of Hb to O₂ is inversely related to acidity and CO₂ concentration

**Lungs:**
High pH, low CO₂ → High affinity → Facilitated O₂-uptake

**Peripheral tissues:**
Low pH, high CO₂ → Low affinity → Facilitated O₂-release
**Oxygen transport within the blood:**

**Red-Cell 2,3-Diphosphoglycerate (DPG)**

- **Glycolysis**
  - Glucose → Glucose-6-phosphate → Fructose-6-phosphate → Fructose-1,6-bisphosphate → Glyceroldehyde-3-phosphate → 2,3-Bisphosphoglycerate → 3-Phosphoglycerate → Pyruvate → Deoxyhemoglobin

- **In normal cells:** negative feedback inhibition of DPG-synthase by 2,3-DPG

- **In red cells:**
  - 2,3-DPG is sequestered by Hb
  - no feedback inhibition

- **In normal red cells:** marginal significance

- **Transfusion:**
  - Inhibition of glycolysis by hypothermia during storage → DPG-production → Left-shift of Hb-O₂-dissociation curve

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**Oxygen transport within the blood**

**Dissociation curves**

- **Fetal Hb:**
  - Leftward shift → Facilitated O₂-uptake at low PO₂ in placenta

- **Myoglobin:**
  - O₂-release only at PO₂ <15-30mmHg (at exercise)

- **Carboxyhemoglobin:**
  - Extremely high affinity of Hb for CO
Oxygen transport within the blood

Oxygen saturation

\[ SpO_2 = \frac{HbO_2}{HbO_2 + Hbdeoxy} \]
\[ = 98 - 100\% \]

Dual wave oxymeter

\[ SaO_2 = \frac{HbO_2}{HbO_2 + Hbdeoxy + MetHb + COHb + SulfHb} \]
\[ = 96 - 98\% \]

Multiwave oxymeter

Oxygen transport within the blood

Oxygen saturation: How to measure?

Pulse oximetry

Light Emitting Diode
Finger
Probe Body
Photodetector
Oxygen transport within the blood
Oxygen saturation: Pulse oximetry

- **Plethysmography**
  - Pulsatile flow: discrimination art/ven bloed en weefsel

- **Spectrophotometry**
  - Principle: light extinction is dependent upon concentration of light absorbing substance (Lambert-Beer's law)
  - OxyHb primarily absorbs IR light (940 nm)
  - DesoxyHb primarily absorbs red light (660nm)
Oxygen transport within the blood
Oxygen saturation: Pulse oximetry

### Spectrophotometry

Calculation of absorption ratio 660/940 nm

<table>
<thead>
<tr>
<th>SO₂</th>
<th>660 nm (R)</th>
<th>940 nm (IR)</th>
<th>R/IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td></td>
<td></td>
<td>~3.4</td>
</tr>
<tr>
<td>85%</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td></td>
<td>0.43</td>
</tr>
</tbody>
</table>

Pulsing blood modulates red and IR light:
- High SaO₂: Red pulse amplitude is smaller.
- Low SaO₂: Infrared pulse amplitude is smaller.

Pulse oximeters measure R and then estimate SaO₂ by applying a multistep transformation curve.

Limitations:
- **Methemoglobin (metHb)**
  - Absorbs R en IR light 1:1 => sat 85%
  - Falsely low values
- **Carboxyhemoglobin (HbCO)**
  - Imitates absorption characteristics of HbO₂
  - Falsely high values
Oxygen transport within the blood

Oxygen saturation: Pulse oximetry

Accuracy
- <2% bias at SO₂ > 90%
- Saturation < 80% → bias ≥ 5%

Limitations:
- Shape of oxygen dissociation curve
- Carboxyhemoglobin
- Methemoglobin
- Anemia
- Dyes
- Nail polish
- Ambient light
- False alarms
- Motion artifact
- Skin pigmentation
- Low perfusion state

Hgb-CO & Hgb-O₂ have similar absorbance at 666nm so Hgb-CO will be falsely interpreted as Hgb-O₂ (high sat)

Absorption characteristics falsely account for a low sat in the patient with Hgb-Met
Oxygen transport within the blood

Oxygen-combining capacity of hemoglobin

Hüfner’s constant

1 mol Hb = 4 mol O₂
1 mol O₂ ≈ 22.4 l
1 mol Hb ≈ 89.6 l
1 mol Hb ≈ 64500 g

1 g Hb ≈ 1.31 ml O₂
≈ 1.34
≈ 1.39

Oxygen transport within the blood

Oxygen content

\[ \text{CaO}_2 = \text{physically diss. O}_2 + \text{chemically bound O}_2 \]

\[ \text{CaO}_2 = \alpha \times \text{PO}_2 + (\text{SaO}_2 \times [\text{Hb}] \times 1.31) \]

\[ \text{ml/dl} \quad \text{ml/dl} \times \text{mmHg} \]

\[ = 0.003 \times 100 \quad + (0.98 \times 15 \times 1.31) \]

\[ = 0.3 \quad + 19.26 \]

\[ \text{CaO}_2 \approx 20 \text{ ml/dl} \]

\[ \text{CvO}_2 = \alpha \times \text{PO}_2 + (\text{SvO}_2 \times [\text{Hb}] \times 1.31) \]

\[ = 0.003 \times 40 \quad + (0.75 \times 15 \times 1.31) \]

\[ = 0.12 \quad + 14.74 \]

\[ \approx 15 \text{ ml/dl} \]

\[ \text{avDO}_2 = 5 \text{ ml/dl} \]

\[ \text{O}_2 \text{ER} = 25\% \]
Oxygen transport within the blood

Oxygen content

When oxygen is too low....

Hypoxia = ↓ PaO₂
Hypoxygenation = ↓ SpO₂
Hypoxemia = ↓ CaO₂
Ischemia = ↓ No blood flow

Hypoxemia

Hypoxic

CaO₂ = α * PaO₂ + (SaO₂ * Hb * 1.31)

Anemic

Toxic: HbCO, Met-Hb
Tolerance: Anemic (Right-shift) > Hypoxic > Toxic (Left-shift)
Oxygen transport within the blood

Oxygen delivery

\[ \text{DO}_2 = \text{Cardiac output} \times \text{Arterial oxygen content} \]
\[ \text{ml/min} \times \text{l/min} \times (\text{ml/dl} \times 10) \]
\[ = 5 \times (20 \times 10) \]
\[ \text{DO}_2 \approx 1000 \text{ ml/min} \]

\[ \text{VO}_2 = \text{Cardiac output} \times \text{avDO}_2 \]
\[ = 5 \times (5 \times 10) \]
\[ \approx 250 \text{ ml/min} \]

\[ \text{O}_2 \text{ER} = \frac{\text{VO}_2}{\text{DO}_2} \]
\[ = 25\% \]

When oxygen delivery is too low....

Increase in oxygen extraction
Decrease in central (mixed) venous oxygen saturation
Oxygen cascade:
The last step: Diffusion into cell

Factors affecting extraction ratio of oxygen from capillary blood:
- Rate of oxygen delivery to the capillary
- Oxygen-haemoglobin dissociation relation
- Size of the capillary to cellular Po2 gradient
- Diffusion distance from the capillary to the cell
- Rate of use of oxygen by cells

Summary of oxygen cascade
Summary of oxygen cascade

1 kPa = 7.5 mmHg

What can we do to improve $DO_2$?

Factors needing to be maintained to prevent tissue hypoxia:
- Oxygen saturation
- Cardiac output
- Haemoglobin concentration
- Oxygen release from haemoglobin
- Extracellular diffusion
- Oxygen use by cells
Carbon Dioxide

- **Volatile waste product of cellular metabolism**
  - \( \text{CO}_2 \) production averages 200 ml/min in resting adult
  - During exercise this amount may increase six-fold
  - Tissue \( P_{\text{tCO}_2} \) is 50 mmHg
  - Diffuses into systemic capillaries with lower PCO\(_2\) levels

Carbon Dioxide Transport

(I) **Dissolved in plasma (7%)**
- 20x more soluble in plasma than \( \text{O}_2 \)
- Solubility coefficient: 0.0007 ml/mmHg/ml
- 2.5 ml \( \text{CO}_2 \) in 100 ml arterial blood

(II) **Diffusion into erythrocyte (93%)**
  a) Binding to hemoglobin (23%)
    \( \rightarrow \) carbaminohemoglobin

\[
\text{R-NH}_2 + \text{CO}_2 \rightleftharpoons \text{RNH} - \text{CO}_2 + \text{H}^+
\]

buffered by reduced hemoglobin
**Carbon Dioxide Transport**

(II) Diffusion into erythrocyte (93%)

b) Reacting to carbonic acid (70%)

\[
\text{CO}_2 + \text{H}_2\text{O} \xleftrightsquigarrow \text{H}_2\text{CO}_3 \xleftrightsquigarrow \text{H}^+ + \text{HCO}_3^-
\]

buffered by reduced hemoglobin

Diffusion into plasma
Exchange for Cl- ions
HAMBURGER SHIFT
Fysiologie van de gasuitwisseling

**Carbon dioxide transport within the blood:**

**Haldane effect**

Hb\textsubscript{deoxy} is a more powerful buffer than HbO\textsubscript{2}

**Affinity of Hb to CO\textsubscript{2}** is inversely related to O\textsubscript{2}-concentration

**Lungs:**
- High O\textsubscript{2} → Low affinity for CO\textsubscript{2} → Facilitated CO\textsubscript{2}-release

**Peripheral tissues:**
- Low O\textsubscript{2} → High affinity for CO\textsubscript{2} → Facilitated CO\textsubscript{2}-uptake

**CO\textsubscript{2} Equilibrium Curve**

- Different from HbO\textsubscript{2} curve
  - Relationship is linear
  - Venous blood transports more CO\textsubscript{2} than arterial blood

- CO\textsubscript{2} equilibrium is affected by O\textsubscript{2} saturation of Hb
  - Ability to bind CO\textsubscript{2} increased in Hb\textsubscript{deoxy}
  - Deoxygenated Hb is weaker acid than oxygenated Hb

- A-a PCO\textsubscript{2} levels not as affected by V/Q mismatch
  - Diffusing capacity 20x greater with CO\textsubscript{2} than O\textsubscript{2}

\[ \text{PO}_2 = 100 \text{mmHg} \]
\[ \text{PO}_2 = 40 \text{mmHg} \]
**Carbon Dioxide Delivery**

**Monitoring CO₂ Transport & Delivery**

**Capnography**

- **Infrared absorption spectroscopy**
  - CO₂ absorbs IR-light (wavelength 4.26 μm)
  - Measurement of absorption within exhaled air and in test gas (known CO₂-concentration)
  - Amount of absorption related to CO₂-concentration (Lambert-Beer’s law)
  - Before measurement: calibration with test gas
**Monitoring CO\textsubscript{2} Transport & Delivery**

**Capnography**

- **Measurement locations**
  - Mainstream
  - Sidestream

- **Accuracy**
  - ± 2 mmHg

- **Limitations**
  - Correction for barometric pressure required
  - Obstruction of sample line by water/secretions
  - Interference with CO, N\textsubscript{2}O, H\textsubscript{2}O and volatile anesthetics (do also absorb IR light)
  - Consider sampling time (dependent upon length of sample line, flow and viscosity of gases)
Monitoring CO₂ Transport & Delivery
Capnogram

- Phase I: Inspiration
  - No CO₂ detected (hopefully)
- Phase II: Appearance of CO₂ in the system.
  - Mixed alveolar and deadspace gas.
- Phase III: Plateau
  - Constant emptying of alveolar gas.
  - Presence of CO₂ through the end of the breath.
- Phase IV: Washout of CO₂ from subsequent inspiration.
Capnography provides instantaneous information about:

- **Ventilation:**
  how effectively is CO$_2$ eliminated by the pulmonary system?

- **Perfusion:**
  how effectively is CO$_2$ transported to the lungs?

- **Metabolism:**
  how effectively is CO$_2$ produced by cellular metabolism?

- **Equipment**
What you learnt today

- Oxygen cascade
- PiO₂
- PAO₂
- Diffusion
- ΔAaPO₂: Shunt
- Oxygen transport / content / delivery
- Pulse oximetry
- Therapeutic principles to improve oxygenation
- CO₂-transport
- Capnography

Suggested readings

(and sources of figures)

- Nunn’s Applied Respiratory Physiology
- Respiratory Physiology: The Essentials
Pressure of inspired oxygen (PiO$_2$)

Oxygen cascade at high altitude

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Beall C

Two routes to functional adaptation: Tibetan and Andean high-altitude natives.

PNAS May 15, 2007 vol. 104 suppl. 1 8655–8660

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Thank you for your attention
**Pressure of alveolar oxygen (PAO₂)**

To maintain PAO₂

↑ VO₂ → ↑ Alv. Vent.

Constant Alv. Vent.

↑ VO₂ → ↓ PAO₂

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**Diffusion:**

**Transit time**

↓ Transit time

↓ Oxygen uptake

↑ Diffusion gradient

↑ Diffusion capacity
Venous admixture
Effects on blood gases

PO$_2$
- Minor changes in CaO$_2$
- Marked effects on PaO$_2$
- Hypoxemia responds poorly to added inspired O$_2$
- When 100% O$_2$ is inspired, the arterial PO$_2$ does not rise to the expected level

PCO$_2$
- Even major changes in CaCO$_2$
- Minimal effects on PaCO$_2$