Objectives

- Outline the determinants of oxygen balance
- Recognize disorders of oxygen delivery
- Identify principles and limitations of techniques for monitoring oxygen balance
- Explain the use of acid-base status in monitoring the seriously ill patient
Case Study 1

- 67-year-old woman status post cholecystectomy 1 day ago
- Develops shortness of breath and altered mental status
- Vital signs: HR 136 beats/min, BP 106/55 mm Hg, RR 28 breaths/min, SpO₂ 91% (room air)
- Benign abdominal examination

What monitoring should be immediately implemented?
What monitoring should be immediately implemented? (Select all that apply)

A. Blood pressure
B. Heart rate
C. Respiratory rate
D. Oxyhemoglobin saturation
E. Temperature
F. Intra-abdominal pressure
Case Study 1

67-year-old woman status post cholecystectomy 1 day ago

Develops shortness of breath and altered mental status

Vital signs: HR 136 beats/min, BP 106/55 mm Hg, RR 28 breaths/min, SpO₂ 94% (room air)

Benign abdominal examination

What monitoring should be immediately implemented?

What are the goals of monitoring in this patient?
Tissue Oxygenation

Cannot be directly measured or monitored

Which component of oxygen balance is more likely to be modified by clinical interventions?
Determinants of O$_2$ Delivery

- Cardiac output (blood flow)
- O$_2$ content of arterial blood
  - Hemoglobin
  - Oxyhemoglobin saturation
  - Pao$_2$
Arterial $O_2$ Content

- **Red blood cell**
  - **Hemoglobin**
  - **Oxygen**

**Saturation 65%-75%**

**Saturation 95%-100%**

- **Venous**
- **Arterial**
- **Tissues**

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\[ \text{SvO}_2 = \text{SaO}_2 - \frac{\text{VO}_2}{1.34 \times (CO)(Hb)} \]

\[ \text{VO}_2 = \text{CO} \times (\text{CaO}_2 - \text{CvO}_2) \]

\[ \text{CaO}_2 = (\text{SaO}_2 \times 1.36 \times \text{Hb}) + (0.003 \times \text{PaO}_2) \]

\[ \text{CvO}_2 = (\text{SvO}_2 \times 1.36 \times \text{Hb}) + (0.003 \times \text{PvO}_2) \]

- 1.36 mL of O\textsubscript{2} can be carried per 1 gram of Hb
- Solubility of O\textsubscript{2} in blood
- Oxygen pressure
Oxygen Reserve

Oxygen unloaded from hemoglobin during normal metabolism

Oxygen reserves that can be unloaded from hemoglobin to tissues with increased demands
Cardiac Output

Heart Rate × Stroke Volume

Preload

Venous return

Ventricular compliance

Afterload

Contractility

Arterial pressure
Importance of Preload

- Preload also affects contractility
Case Study 1

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How would you evaluate oxygen delivery in this patient?
How would you evaluate oxygen delivery in this patient? (Select all that apply)

A. Heart rate
B. Mean arterial pressure
C. Venous blood gas analysis
D. Pulse oximetry
Case Study 1

- 67-year-old woman status post cholecystectomy 1 day ago
- Develops shortness of breath and altered mental status
- Vital signs: HR 136 beats/min, BP 106/55 mm Hg, RR 28 breaths/min, SpO\textsubscript{2} 94% (room air)

How would you determine oxygen delivery in this patient?

- Cardiac output
- Arterial oxygen content
Pulse Oximetry

What does a pulse oximeter measure?

$\text{SpO}_2$ vs $\text{SaO}_2$

What factors might affect the accuracy of the pulse oximeter measurement?
Blood Pressure Measurement

- Blood pressure = cardiac output x systemic vascular resistance

What options would you consider for monitoring blood pressure in this patient?

- Manual noninvasive device
- Automated noninvasive device
- Arterial cannulation
Case Study 1

- Automated blood pressure device and pulse oximeter applied
- $\text{SpO}_2$ 91% (room air), HR 135 beats/min, BP 96/50 mm Hg
- Hemoglobin 11.5 g/dL

Is oxygen delivery sufficient to maintain an adequate oxygen balance?
Is oxygen delivery sufficient to maintain adequate oxygen balance? (Choose the best answer)

A. Yes
B. No
C. More information is needed
Case Study 1

- Automated blood pressure device and pulse oximeter applied
- $\text{SpO}_2$ 91% (room air), HR 135 beats/min, BP 96/50 mm Hg
- Hemoglobin 11.5 g/dL

Is oxygen delivery sufficient to maintain an adequate oxygen balance?
Tissue Oxygenation

- Central venous oxyhemoglobin saturation (ScvO$_2$)
- Lactate concentration
Venous Oxyhemoglobin Saturation

Saturation 100%

Saturation 65%-75%

Venous

Arterial

Red blood cell

Hemoglobin

Oxygen

Tissues
Central Venous Oxyhemoglobin Saturation

**What does a low ScvO₂ mean?**

**What does a normal ScvO₂ mean?**
Lactate

- Product of anaerobic metabolism with cellular hypoxia
- Elevated concentrations
  - Inadequate oxygen supply
  - Drugs
  - Hepatic dysfunction

Mortality vs. Lactate
Case Study 1

- Repeat vital signs: HR 135 beats/min, BP 96/50 mm Hg, RR 28 breaths/min, T 101°F (38.3°C), SpO₂ 92% (6 L/min nasal cannula)
- Arterial blood gas: pH 7.32, Paco₂ 32 mm Hg (4.3 kPa), PaO₂ 68 mm Hg (9.1 kPa)
- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO₃⁻ 16 mmol/L, BUN 28 mg/dL, creatinine 1.4 mg/dL

Does the acid-base status suggest the patient is seriously ill?
Acid-Base Analysis

- Determine overall acid-base condition (acidemia or alkalemia)
- Determine if primary process is metabolic or respiratory
- Determine if acute or chronic process in respiratory disturbance
- Determine if respiratory compensation adequate in metabolic process
- Calculate anion gap (always)
Acid Base 101

Look at the pH.

*Expect an increase in the bicarbonate by 1 meq/L for every 10 mm Hg rise in the PaCO₂ in respiratory acidosis.*

Calculate the anion gap.

*Greater than or equal to 20 → metabolic acidosis no matter what.*

*The body does not generate a large enough anion gap to compensate for a primary disorder.*

Calculate the excess anion gap (Δ gap).

*12 (10-14) is the standard, so subtract the anion gap from 12.*

*Next, add this value to your measured bicarbonate. If this is greater than 30, you have an underlying metabolic alkalosis.*

*If this is less than 23 (a normal bicarbonate value), you have an underlying NON gap metabolic acidosis.*

*The reason for this is because 1 mmol of unmeasured acid should titrate 1 mmol of bicarbonate; hence a Δ anion gap should equal the Δ bicarb under normal circumstances.*
Measured Anion Gap – 12

> 30

Underlying metabolic ALKalosis

< 23

Underlying NON gap metabolic ACIDosis

\[ \text{AG} = [\text{Na}^+ + \text{K}^+] - [\text{Cl}^- + \text{HCO}_3^-] \]
Metabolic Acidosis

*If you are still second guessing yourself, use Winter’s formula for metabolic acidosis to make sure your PaCO$_2$ is what it should be.*

\[
PaCO_2 = 1.5 \times \text{measured } HCO_3^- + 8 \ (\pm 2)
\]

One other trick for metabolic acidosis: *the expected PaCO$_2$ should approximate the last 2 digits of the pH value. For example, the expected PaCO$_2$ for a primary metabolic acidosis with a pH of 7.25 is 25.*
Stewart Approach

Strong Ion Gap = SID = [strong cations] – [strong anions]

≈ \( \text{Na}^+ - \text{Cl}^- \)

≈ 38 (140-102)

**ACIDOSIS** usually means extra anions.
The strong ion difference is **DECREASED**.
Seen in disorders where cations are decreased (potassium, sodium) or where anions are increased (hyperchloremia, lactatemia, ketoacids, etc.).

**ALKALOSIS** usually means extra cations.
The strong ion difference is **INCREASED**.
Seen in disorders where cations are increased (hyperkalemia, hypercalcemia, hypernatremia) or where anions are decreased (hypoalbuminemia, hypochloremia)
insert new data into the acidbase database
please - be careful choosing the units for your measurements!
there are plenty of different units used around the world - preferentially use SI units!

### Chemical Data

<table>
<thead>
<tr>
<th>Required Data</th>
<th>Optional Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>lithium</td>
</tr>
<tr>
<td><strong>BE (base excess) read more!</strong></td>
<td>Mg</td>
</tr>
<tr>
<td><strong>Na read more! about the influence of serum Na⁺ on its ionic activity</strong></td>
<td>Ca (total, not free or &quot;ionised&quot;) read more!</td>
</tr>
<tr>
<td>normal value for Na</td>
<td>phosphate</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>lactate</td>
</tr>
<tr>
<td><strong>Cl</strong></td>
<td>haemoglobin</td>
</tr>
<tr>
<td>normal value for Cl</td>
<td>osmolality or freeze-point method</td>
</tr>
<tr>
<td><strong>PCO₂</strong></td>
<td>glucose</td>
</tr>
<tr>
<td>albumin the most prominent of the weak acids</td>
<td>urea</td>
</tr>
<tr>
<td></td>
<td>ethanol or other osmotically active substances (1 % ethanol is 21 mosmol/l)</td>
</tr>
</tbody>
</table>

*Required for cross-checking purposes*
*Registering this value is strongly recommended!*
*Only useful for calculatingUX (unknown ion excess) (if not given, a value of 6 mmol/l / 100g/l is assumed.)*
*Only required if you want to calculate the osmotic gap, strongly recommended in cases of intoxication or ketoacidosis*

*Do not register anionic substances like hydroxybutyrate (because their osmotic effect is already accounted for by the corresponding kation)*

*May you make an educated guess about albumin? yes - BUT: read more!*
Case Study 1

- pH 7.32, PaCO₂ 32 mm Hg (4.3 kPa), PaO₂ 68 mm Hg (9.1 kPa)
- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO₃⁻ 16 mmol/L

Acidemia or alkalemia? → Acidemia

Respiratory or metabolic? → Metabolic

Adequate respiratory compensation? → Yes

PaCO₂ = 1.5 [HCO₃⁻] + 8 ± 2 → 1.5 x 16 + 8 = 32
Case Study 1

- pH 7.32, Paco₂ 32 mm Hg (4.3 kPa), PaO₂ 68 mm Hg (9.1 kPa)
- Na 142 mmol/L, K 4.0 mmol/L, Cl 106 mmol/L, HCO₃⁻ 16 mmol/L

**Anion gap?**

\[
AG = [\text{Na}] - ([\text{Cl}] + [\text{HCO}_3^-])
\]

\[
142 - 122 = 20
\]

What is the expected AG if albumin = 2.0 g/dL?

- Expected AG decreases by 2.5-3 mmol/L for every 1 g/dL decrease in albumin
  
  Expected AG = 12 – (5-6) = 6-7
Case Study 1

- Patient is intubated for worsening oxygenation, $\text{SpO}_2$ 95% ($\text{FiO}_2$ 0.60)
- Arterial catheter inserted, BP 92/54 mm Hg
- Central venous catheter inserted
  - Central venous pressure 10 mm Hg
  - $\text{ScvO}_2$ 60%
- Lactate concentration 6 mmol/L

Does the CVP measurement indicate the need for more intravenous fluids?
Does the CVP measurement indicate the need for more intravenous fluids? (Choose the best answer)

A. Yes
B. No
C. Cannot be determined
Case Study 1

- Patient is intubated for worsening oxygenation, \( \text{SpO}_2 \) 95% (\( \text{FiO}_2 \) 0.60)
- Arterial catheter inserted, BP 92/54 mm Hg
- Central venous catheter inserted
  - Central venous pressure 10 mm Hg
  - \( \text{ScvO}_2 \) 60%
- Lactate concentration 6 mmol/L

What other monitoring methods can help in determining fluid responsiveness?
Monitoring Fluid Responsiveness

- Variation in systolic blood pressure, pulse pressure, or stroke volume
  - Mechanically ventilated patients

- Response to increased preload
  - Passive leg raising
  - Fluid boluses
  - Assess change in stroke volume, cardiac output, or blood pressure

- Variation/change >10%-15% suggests responsive to additional fluids
Case Study 1

Arterial waveform tracing on mechanical ventilation

What interventions might be considered?
What interventions might be considered? (Select the single best answer)

A. Administration of vasopressors
B. Administration of IV fluids
C. Administration of sedation
D. Decrease PEEP or tidal volume
Case Study 1

Arterial waveform tracing on mechanical ventilation

What interventions might be considered?
Key Points

- Oxygen delivery is dependent on cardiac output and arterial oxygen content
- Hemoglobin is the major contributor of oxygen for tissue demands
- Normal filling pressures may not indicate adequate preload volume
- $\text{ScvO}_2$ and lactate are useful measures of global oxygen balance
- Low $\text{ScvO}_2$ values suggest oxygen imbalance
Key Points

- Pulse oximetry values do not reflect adequacy of oxygen delivery
- Arterial cannulation is preferred for blood pressure monitoring in unstable patients
- Systolic blood pressure, pulse pressure, or stroke volume variation and fluid responsiveness may help optimize cardiac output and oxygen delivery
- Assessment of acid-base status may suggest specific diagnoses and/or interventions