Arterial blood gas analysis workshop

Learning outcomes
At the end of this workshop candidates should be able to:

- understand the normal ranges for arterial blood gas values
- use the 5-step approach to arterial blood gas interpretation
- identify some common causes of arterial blood gas abnormalities and what to do to correct them

Instructor information
Set the mood; establish usefulness and state learning outcomes for the session.

This workshop is intended as a basic introduction to arterial blood gas interpretation. It focuses on common acid-base abnormalities that occur before, during and immediately after resuscitation from cardiac arrest. It will enable the candidate to make simple and appropriate changes to the patient’s treatment in response to arterial blood gas values.

There are five case studies, work through each using the 5-step approach to arterial blood gas analysis.

Case 1: This covers each of the five steps in detail. However, it is still important to review the information in the handover to answer the question in Step 1, ‘how is the patient?’ This can be used to take the group through the fives steps adding additional explanation at each.

Following Cases: Following an ISBAR-based handover, the patient undergoes an ABCDE assessment during which an arterial blood sample is sent for analysis. This information should be used to answer the question in Step 1, ‘how is the patient’. Then the results of the blood gas reviewed for the following steps.

Allow candidates to ask questions and reflect on the session content before terminating the session with a succinct review of all the major points covered.

NB. The case studies below are based on real patients, but the values have been adjusted slightly to make the abnormalities more obvious and cause less confusion for the candidates. Consequently, they will not conform exactly to calculated analyses of acid base disturbance.
The 5-step approach to arterial blood gas interpretation

1. How is the patient?
   This will provide valuable clues to help with interpretation of the results. Try and predict the effect on the blood gases of the pathological process

2. Assess oxygenation:
   Is the patient hypoxaemic? The PaO$_2$ should be $> 75$ mmHg (10 kPa) on air and about 5 times the % inspired concentration (within about 75 mmHg) as a very rough bedside calculation

3. Determine the pH or H$^+$ concentration:
   Is the patient acidaemic? pH $< 7.35$ (H$^+ > 45$ nmol L$^{-1}$) Is the patient alkalaemic; pH $> 7.45$ (H$^+ < 35$ nmol L$^{-1}$)

4. Determine the respiratory component
   PaCO$_2$ $> 45$ mmHg (6.0 kPa) – respiratory acidosis (or respiratory compensation for a metabolic alkalosis)
   PaCO$_2$ $< 35$ mmHg (4.7 kPa) – respiratory alkalosis (or respiratory compensation for a metabolic acidosis)

5. Determine the metabolic component:
   HCO$_3^-$ $< 22$ mmol L$^{-1}$ – metabolic acidosis (or renal compensation for a respiratory alkalosis)
   HCO$_3^-$ $> 26$ mmol L$^{-1}$ – metabolic alkalosis (or renal compensation for a respiratory acidosis)

Some clinicians prefer to use the base excess (or deficit) instead of the HCO$_3^-$ As the changes in these values usually mirror each other, it makes no significant difference to the interpretation of the clinical condition. The normal base excess is +/- 2 mmol L$^{-1}$.

*Please note the HCO$_3^-$ and BE limits may vary depending on institution. The measurements for the session are taken from common limits used internationally.*

All of the information can then be drawn together to produce a final diagnosis of the primary disturbance, any degree of compensation and any indication of disturbance of oxygenation.

NB. In the cases below, for clarity, only the pH value is given.
Arterial blood gas analysis workshop

Case study 1

Initial information

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>ED staff member has asked you to assist.</td>
</tr>
<tr>
<td>S</td>
<td>21-year-old woman who on the way to hospital has become increasingly drowsy.</td>
</tr>
<tr>
<td>B</td>
<td>She was thrown from her horse at a local event</td>
</tr>
<tr>
<td>A</td>
<td>A: Clear, tolerating an oropharyngeal airway, on 40% oxygen via face mask</td>
</tr>
<tr>
<td>B</td>
<td>B: Respiratory rate 8 min⁻¹, SpO₂ 99%, reduced equal air entry both lungs, percussion note resonant both sides, trachea central</td>
</tr>
<tr>
<td>C</td>
<td>C: Pulse 54 min⁻¹ regular, BP 166/105 mmHg. An arterial blood sample to check her blood gases and acid base status has been taken</td>
</tr>
<tr>
<td>D</td>
<td>D: avpU, Glucose 5.3 mmoll⁻¹, no medications given</td>
</tr>
<tr>
<td>E</td>
<td>E: IV in right forearm, Eyes swollen/bruising. No external bleeding</td>
</tr>
<tr>
<td>R</td>
<td>You take an arterial blood sample to check her blood gases and acid base status.</td>
</tr>
</tbody>
</table>

Instructor information

Use the 5-step approach to guide the candidates through interpretation of the results.

Step 1: How is the patient?

From your ABCDE assessment what might you expect?

- Her reduced level of consciousness may impair oxygenation and ventilation.
- As a result, she may be hypoxic and have an increased PaCO₂ causing a respiratory acidosis and a low pH.
- Compensation (change in bicarbonate) is unlikely because of the acuteness of the situation.
Inspired oxygen 40% (FiO₂ 0.4)

<table>
<thead>
<tr>
<th></th>
<th>normal values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂</td>
<td>110 mmHg</td>
</tr>
<tr>
<td></td>
<td>&gt; 75 mmHg on air</td>
</tr>
<tr>
<td>pH</td>
<td>7.19</td>
</tr>
<tr>
<td></td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>78 mmHg</td>
</tr>
<tr>
<td></td>
<td>35 – 45 mmHg</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>23.6 mmol l⁻¹</td>
</tr>
<tr>
<td></td>
<td>22 – 26 mmol l⁻¹</td>
</tr>
<tr>
<td>Base excess</td>
<td>-2.4 mmol l⁻¹</td>
</tr>
<tr>
<td></td>
<td>+/- 2 mmol l⁻¹</td>
</tr>
</tbody>
</table>

What are you going to do now?

**Step 2: Assess oxygenation**
- Is the patient hypoxaemic?
  - The PaO₂ should be about five times the % inspired concentration. In this patient the gradient is increased suggesting impaired oxygenation.

What are you going to do now?

**Step 3: Determine status of the pH (or H⁺ concentration)**
- Is the patient acidaemic; pH < 7.35?
- Is the patient alkalaemic; pH > 7.45?
  - The patient is acidaemic; pH < 7.35

What are you going to do now?

**Step 4: Determine the respiratory component**
- If the pH < 7.35, is the PaCO₂ > 45 mmHg (6.0 kPa)? – respiratory acidosis.
- If the pH > 7.45, is the PaCO₂ < 35 mmHg (4.7 kPa)? – respiratory alkalosis.
  - The pH < 7.35, and the PaCO₂ > 45 mmHg (6.0 kPa) indicating a respiratory acidosis

What are you going to do now?

**Step 5: Determine metabolic component**
- If the pH < 7.35, is the HCO₃⁻ < 22 mmol L⁻¹ (base excess < -2 mmol L⁻¹)? – metabolic acidosis.
- If the pH > 7.45, is the HCO₃⁻ > 26 mmol L⁻¹ (base excess > +2 mmol L⁻¹)? – metabolic alkalosis.
  - The pH < 7.35, but the HCO₃⁻ is within normal limits, indicating no metabolic disturbance or compensation.

**In summary:**
- The patient has an acute respiratory acidosis with impaired ventilation. (Oxygenation is good as PaO₂ normal – ventilation impaired).
- Because of the acuteness of the situation, there is no compensation.
Respiratory arrest

**Initial information**

I: You have been called to a medical emergency

S: “A patient is currently in respiratory arrest”.

B: Patient admitted with COPD - initial assessment by the ward nurse he was found to be apnoeic.

A: Apnoeic - head tilt chin lift opening manoeuvre

B: Nurse is attempting to ventilate with bag-mask, oxygen at 15 l min⁻¹, Oropharyngeal airway, SaO₂ 90%. Widespread wheeze in both lungs and coarse crackles at the left base.

C: Easily palpable carotid pulse – 56 bpm – regular (not monitored) Capillary refill < 3 seconds, IV inserted, BP not recorded (150/94 earlier)

D: AVPU, Glucose 6.2 mmoll⁻¹, no medications given recently

E: Nil. IV in right forearm

R: Please review urgently and an arterial blood gas sample has been taken

Use the 5-step approach to analyse the results of the arterial blood sample

Arterial blood gas sample taken while he is ventilated with 85% oxygen reveals:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inspired oxygen 85% (FiO₂ 0.85)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaO₂</td>
<td>147 mmHg</td>
<td>&gt; 75 mmHg on air</td>
</tr>
<tr>
<td>pH</td>
<td>7.10</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>135 mmHg</td>
<td>35 – 45 mmHg</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>36 mmol l⁻¹</td>
<td>22 – 26 mmol l⁻¹</td>
</tr>
<tr>
<td>Base excess</td>
<td>+12 mmol l⁻¹</td>
<td>+/- 2 mmol l⁻¹</td>
</tr>
</tbody>
</table>

**Instructor information**

Use the 5-step approach to guide the candidates through interpretation of the results.

**Step 1: How is the patient?**

From the ABCDE assessment what might you expect?

- Impaired oxygenation due to his underlying lung disease.
- An increased PaCO₂ as a result of the period of apnoea and his COPD.
- A reduced pH.
- Signs of compensation for his chronic respiratory acidosis due to his COPD with an increased bicarbonate.
Step 2: Assess oxygenation
- The patient is hypoxic, \( \text{PaO}_2 \) 147 mmHg, and the gradient between inspired oxygen and expected \( \text{PaO}_2 \) is increased indicating impaired oxygenation.

Step 3: Determine the pH (or H⁺ concentration)
- The patient is acidaemic; pH < 7.35

Step 4: Determine the respiratory component
- The pH < 7.35, and the \( \text{PaCO}_2 \) > 45 mmHg indicating a respiratory acidosis.

Step 5: Determine the metabolic component
- The pH < 7.35, but the \( \text{HCO}_3^- \) and base excess are both significantly increased, indicating a metabolic alkalosis.

In summary:
- He is hypoxic.
- He has a significant acidaemia.
- There is an acute respiratory acidosis as a result of the respiratory arrest.
- There is a metabolic alkalosis from his pre-existing, compensated, chronic respiratory acidosis.

Treatment will include:
- If appropriate, tracheal intubation and ventilation or if/when self-ventilating consider non-invasive ventilation.
**Ventilated post VF arrest**

**Initial information**

I: ED staff call for assistance

S: Mrs Harris, 86, who has been successfully resuscitated after an out-of-hospital cardiac arrest. ROSC was achieved after a three shocks, but she didn’t regain consciousness so she was intubated before transfer.

B: The arrest witnessed by paramedics had been preceded by 30 min of severe central chest pain

A: intubated, 7.5 mm diameter tube, 22 cm at lips

B: manual ventilation, about 18 to 20 breaths min\(^{-1}\)/emptying about 750 ml of bag each time, end-tidal CO\(_2\) 23 mmHg, good air entry both lungs, SpO\(_2\) 97%

C: pulse 126 min\(^{-1}\), sinus tachycardia, blood pressure 94/68 mmHg, IV present

D: AVPU, no eye opening (1), intubated (\(-\)), extending to pain (2) – GCS 4

E: nothing gross. IV in left antecubital fossa. Adrenaline and amiodaone given as per algorithm

R: Please review urgently and an arterial blood gas sample has been taken

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**Use the 5-step approach to analyse the results of the arterial blood sample**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspired oxygen</td>
<td>100% (FiO(_2) 1.0)</td>
</tr>
<tr>
<td>PaO(_2)</td>
<td>192 mmHg</td>
</tr>
<tr>
<td>pH</td>
<td>7.62</td>
</tr>
<tr>
<td>PaCO(_2)</td>
<td>20 mmHg</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>19 mmol l(^{-1})</td>
</tr>
<tr>
<td>Base excess</td>
<td>-4 mmol l(^{-1})</td>
</tr>
</tbody>
</table>

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**Instructor information**

Use the 5-step approach to guide the candidates through interpretation of the results.

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**Step 1: How is the patient?**

From the ABCDE assessment what might you expect?

- Impaired oxygenation due to complications of the arrest e.g. aspiration.
- A low PaCO\(_2\) due to the excessive ventilation.
- An alkalaemia and raised pH from the excessive ventilation.
- A metabolic acidosis from anaerobic respiration during the cardiac arrest.
- A low bicarbonate as it will have been consumed to try and buffer the acidosis.
Step 2: Assess oxygenation

- The patient is well oxygenated, but there is a significant gradient suggesting impaired oxygenation.

Step 3: Determine the pH (or H⁺ concentration)

- The patient is alkalaemic; pH > 7.45.

Step 4: Determine the respiratory component

- The PaCO₂ < 35 mmHg indicating a respiratory alkalosis.

Step 5: Determine the metabolic component

- The pH > 7.45, but the HCO₃⁻ and base excess are both slightly reduced, indicating a slight metabolic acidosis.

**In summary the patient has:**

- A respiratory alkalosis from the excessive ventilation.
- A mild metabolic acidosis.
- Impaired oxygenation, despite a PaO₂ in the normal range.

**Treatment will include:**

- Reduction of the FiO₂, aim for 'normal' PaO₂.
- Reduce the minute volume; set a tidal volume of about 500 ml and rate of 10-12 breaths min⁻¹.
  Further adjustments made depending on the results of repeat ABGs.
Diabetic patient

Initial information

I: You have been called as carers for a patient are concerned

S: A 21-year old insulin dependent diabetic is unwell. Mr George is an insulin dependant who has been vomiting for 48 hours. Because he was unable to eat, he has taken no insulin.

A: airway clear/patent

B: breathing spontaneously RR 32 min⁻¹, oxygen 6 l min⁻¹ via Hudson mask, SpO₂ 98% . Obvious smell of ketones on his breath

C: cold and clammy, pulse 120 min⁻¹, BP 90/66 mmHg, IV in left hand - saline running at rate of 50 ml per hour

D: AVPU (Alert earlier), Eye opening to speech (3), confused (4), obeys commands (6), GCS 13. ”No insulin given” recorded, bedside Blood sugar “Hi”

E: slightly distended abdomen, tender on examination, no bowel sounds.

R: Please review urgently and an arterial blood gas sample has been taken

Use the 5-step approach to analyse the results of the arterial blood sample

<table>
<thead>
<tr>
<th></th>
<th>normal values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inspired oxygen 30% (FiO₂ 0.3)</strong></td>
<td></td>
</tr>
<tr>
<td>PaO₂</td>
<td>129 mmHg</td>
</tr>
<tr>
<td>pH</td>
<td>6.89</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>19 mmHg</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>4.7 mmol l⁻¹</td>
</tr>
<tr>
<td>Base excess</td>
<td>-29.2 mmol l⁻¹</td>
</tr>
</tbody>
</table>

The blood glucose is 30 mmol L⁻¹ and there are ketones +++ in the urine.

Instructor information

Use the 5-step approach to guide the candidates through interpretation of the results.

Step 1: How is the patient?

Knowing that the patient has type 1 diabetes the following might be present:

- He is likely to be acidaemic with a low pH.
- He will be trying to compensate by hyperventilating and have a low PaCO₂.
- He will have a reduced bicarbonate as a result of buffering the ketoacids.
- No significant impairment of oxygenation.
Step 2: Assess oxygenation

- The patient is well oxygenated, with no evidence of any impaired oxygenation.

Step 3: Determine the pH (or H+ concentration)

- The pH is < 7.35 and patient is profoundly acidaemic.

Step 4: Determine the respiratory component

- The PaCO₂ < 35 mmHg indicating a respiratory alkalosis.

Step 5: Determine the metabolic component

- The HCO₃⁻ and base excess are both significantly reduced indicating a severe metabolic acidosis.

In summary:

- There is no impairment in oxygenation.
- He has a primary metabolic acidosis with partial respiratory compensation as his pH remains low.
- These blood gas results are consistent with severe diabetic ketoacidosis.
- Further evidence is the presence of ketones in his urine and the very high blood glucose.

Treatment would include:

- Fluid resuscitation, initially with normal saline
- Insulin, with regular measurement of blood glucose
- The use of bicarbonate is controversial but some clinicians would give it in the presence of such a severe acidaemia, particularly if it did not improve rapidly after starting the above measures.
Out of hospital witnessed arrest

Initial information

I: You are met by one of the nurses in ED who gives you the following handover

S: This is Mr Brown, 63, who has been successfully resuscitated after an out-of-hospital cardiac arrest.

B: He arrested about 20 min ago, had bystander CPR for about 5 min. When the paramedics arrived he was in VF and got ROSC after the second shock.

A: A: he is intubated, on 50% oxygen RR 8-10

B: saturation 98%

C: systolic blood pressure 130 mmHg, HR 120 min⁻¹. He’s had about 750 ml saline IV.

D: AVPU, Glucose 6.8, Adrenaline 1mg post 2nd shock

E: cyanosed. Temp 35.7 °C

R: A 12-lead ECG has been requested and some blood gases have been sent

Use the 5-step approach to analyse the results of the arterial blood sample

<table>
<thead>
<tr>
<th>Inspired oxygen 50% (FiO₂ 0.5)</th>
<th>normal values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂ 56 mmHg</td>
<td>&gt; 75 mmHg on air</td>
</tr>
<tr>
<td>pH 7.10</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO₂ 47 mmHg</td>
<td>35 – 45 mmHg</td>
</tr>
<tr>
<td>Bicarbonate 14 mmol l⁻¹</td>
<td>22 – 26 mmol l⁻¹</td>
</tr>
<tr>
<td>Base excess -10 mmol l⁻¹</td>
<td>+/- 2 mmol l⁻¹</td>
</tr>
</tbody>
</table>

Instructor information

Use the 5-step approach to guide the candidates through interpretation of the results.

Step 1: How is the patient?

From the ISBAR handover what might you expect?

- Hypoxaemia as a result of aspiration, pulmonary oedema, pneumothorax, alone or in combination.
- An increased PaCO₂ due to a period of hypoventilation.
- A low pH as a result the anaerobic metabolism during the arrest.
- Consumption of bicarbonate in an attempt to buffer the acidaemia.
Step 2: Assess oxygenation

- The patient is hypoxic, PaO$_2$ 56 mmHg, and the gradient between inspired oxygen and PaO$_2$ is increased indicating impaired oxygenation.

Step 3: Determine the pH (or H$^+$ concentration)

- The patient is acidaemic; pH < 7.35

Step 4: Determine the respiratory component

- The pH < 7.35, and the PaCO$_2$ > 45 mmHg indicating a respiratory acidosis. This is only minimal, as a result of being ventilated.

Step 5: Determine the metabolic component

- The pH < 7.35, and the HCO$_3^-$ and base excess are both significantly decreased, indicating a metabolic acidosis.

In summary:

- This is a typical ABG result after prolonged cardiac arrest
- There is significant impairment of oxygenation
- There is a mixed metabolic and respiratory acidosis – the predominant component is metabolic

Treatment will include:

- Increase the FiO$_2$ – this should increase the PaO$_2$.
- Increase the minute ventilation to reduce the PaCO$_2$ – this will quickly increase the pH.
- Optimise the cardiac output – increased oxygen delivery to the tissues will restore aerobic metabolism, reduce the lactic acidosis and slowly restore the pH towards normal.
- Bicarbonate is not indicated as restoring cardiac output will restore plasma bicarbonate.

Session summary

This workshop has covered:

- The terms used to describe the results of arterial blood gas analysis.
- The normal ranges for arterial blood gas values.
- How to use the 5-step approach to arterial blood gas interpretation.
- Some common causes of arterial blood gas abnormalities and what to do to correct them.