ARTERIAL BLOOD PRESSURE MONITORING

A LEARNING RESOURCE FOR

INTENSIVE CARE NURSING STAFF

Mairi Mascarenhas Clinical Educator ICU
Intensive Care Unit
Raigmore Hospital

Reviewed: February 2018
Indications for arterial blood pressure monitoring:

- Any major medical or surgical condition that compromises cardiac output, tissue perfusion or fluid volume status.
- Patients requiring continuous monitoring of blood pressure due to difficulties in obtaining blood pressure recordings by the cuff method.
- When frequent arterial blood gas sampling is required.
- When vasoactive/inotopic therapy is required.

Insertion sites for arterial puncture/cannulation include:

1. Radial artery.
2. Axillary artery: this becomes the brachial artery at the level of the teres major muscle.
5. Dorsalis pedis artery.
Arterial catheters:

1. Vygon leader cath
2. Baxter flow-switch

An arterial catheter (line) is a sterile tube that is inserted into an artery, enabling direct access to the artery and allows connection to a fluid-filled transducer monitoring kit.

Safety points to consider when the arterial line is inserted:

- No arterial line should be left in situ without attachment of a flush administration set. Always have a flush administration set prepared in advance before the arterial line is inserted.
- The administration set must be free from air including the dead space in the 3-way tap ports. All ports should be sealed using the appropriate bungs (rather than the dust caps that are used during priming). Ensure all connections are tight and secure.
- Red coloured caps should be used for arterial line port-holes thus helping prevent wrong-route errors.
- The transducer flush solution must be prescribed. The prescription is always 500ml 0.9% sodium chloride. The solution must be checked and signed for by 2 registered nurses. Never use any other flush solution other than 500ml 0.9% sodium chloride and always check the fluid bag against the prescription. Errors have occurred where a glucose solution has been connected resulting in blood sampling errors and patients receiving inappropriate treatments.
- The volume remaining in the transducer flush solution must be checked regularly and a new bag of fluid should be connected as appropriate. Special attention needs to be made where ambient lighting is reduced or during night time hours. Failure to check the volume of fluid remaining may result in a blocked arterial line.
- The flush administration set is changed every 96 hours. The arterial line dressing is changed every 96 hours.
- The arterial cannula site should be dressed with a sterile vapour permeable transparent dressing to allow insertion site inspection. The arterial line may or may not be sutured to the skin. This should be recorded in the arterial bundle documentation and should also be highlighted in the alert box on the patient’s observation chart.
- **Never** inject anything into an arterial line. The result of an accidental injection will depend on what has been injected but it has the potential to cause cardiac arrest.
- Where possible the cannula (limb) should be exposed and continually observed.
- Immediately report any blanching of the limb to medical staff.
- If the arterial cannula is no longer required it should be removed immediately.
Radial artery catheterisation:

The radial artery is the preferred site for insertion because of low complication rates.

Technique of radial line insertion:

After cleaning the skin with chloraprep 2%, lignocaine 1% is infiltrated over the radial artery. There are 3 common insertion techniques. Whichever technique is used, the cannula should never be forced along the artery as local damage may occur.

1. Direct cannulation: insertion technique similar to that of a venous cannula. Extension of the wrist brings the artery closer to the surface. Stabilising the wrist in this position either with tape or with the aid of an assistant makes insertion easier. The radial artery is palpated. The cannula is inserted aiming to hit the middle of the artery at an angle of approximately 30° to the skin. Where there is free flow of arterial blood back into the hub of the cannula, the cannula sheath is advanced over the needle into the artery.

2. Transfixion: after obtaining a flashback, the cannula is advanced through the posterior wall of the artery. The needle is removed and a syringe attached. The cannula is slowly withdrawn while aspirating. Once free aspiration is achieved, the cannula is advanced proximally along the artery. This is a particularly useful technique in paediatric patients.

3. Guidewire (Seldinger) technique: a guidewire may be used if advancement of the cannula sheath over the needle proves difficult, for example in atheromatous disease. The guidewire is inserted through the cannula sheath after removal of the needle (or through needles which are provided in some arterial cannulation sets). The guidewire should advance freely along the artery. The cannula sheath is then advanced along the artery, and the guidewire is removed.

The arterial line is then made secure either by using (1) suture or (2) adhesive strips. A sterile dressing is placed over the insertion site. The transducer flush is immediately connected. If the arterial cannula is not stitched in place, this must be highlighted in the alert box on the patient’s observation chart. The arterial line insertion checklist/sticker is completed and placed in the patient’s medical notes.

### ARTERIAL LINE INSERTION
COMPLETE ALL INFORMATION

Date: __________ Time: __________

Inserted by: __________

Type of cannula: __________ Sutures in situ: Yes/No

Position of cannula: __________ Blood cultures: Yes/No.

Procedure:

Correct hand hygiene: Y/N
Apron and sterile gloves: Y/N
Chloraprep used: Y/N
Sterile field maintained: Y/N
Sterile technique used to apply dressing: Y/N

Arterial lines must be clearly identified.

Red coloured caps should be used for arterial line port-holes thus helping prevent wrong-route errors.
Advantages of invasive BP measurement:

- Invasive BP measurement allows beat-to-beat blood pressure monitoring, a visible waveform, allowing a more detailed analysis of the patient’s cardiovascular system to be made.
- Indirect techniques can often underestimate/overestimate pressure recordings.
- Cuff pressures lose accuracy in the presence of shock, arrhythmias, vasoconstrictor drugs or calcified arteries.

The monitoring system consists of 4 main parts:

1. The indwelling invasive catheter/cannula.
2. The transducer which receives the signal from the tubing and converts it into electrical energy.
3. The flush system which maintains catheter patency.
4. The bedside monitor which displays the waveform.

Flush system/transducer set:

- Inflate the pressure infusor bag to 300mmHg (for adult management).
- An inflation pressure of 300mmHg will allow a continuous flush of 3mls/hr to keep the arterial line patent and fit for use.
- Inflate the pressure infusor bag to 150mmHg (for paediatric management).
- An inflation pressure of 150mmHg will allow a continuous flush of 1.5mls/hr to keep the arterial line patent and fit for use.

The transducer must be zeroed correctly and levelled at a known reference point:

- The right atrium is used as a reference point for arterial catheters.
- The position of the right atrium is estimated at the phlebostatic axis which intersects at the midaxillary line and the 4th intercostal space.
Patient position:

- Recordings can be reliably measured at head-of-bed positions 0 to 60°.
- If patients are nursed on a lateral position, it is then difficult to determine the exact/true phlebostatic axis.
- For this reason, measurements are not considered as accurate in lateral positions compared to those taken with a patient lying supine.

Calibrating/zeroing procedure:

- Locate the phlebostatic axis at intersection of midaxillary line and 4th intercostal space.
- Turn the 3-way tap off to the patient and remove the cap from the 3-way port.
- Press the zero key on the monitor. Look for a display indicating that zeroing has occurred.
- Replace the cap on the 3-way tap and turn the stopcock on to the patient.
- Observe the waveform and document the blood pressure measurements including the MAP.

The transducer must be calibrated:

- Following insertion of an arterial cannula.
- At the beginning of every shift.
- Whenever the patient’s position is changed.
- When the transducer set is changed.
- If there is any doubt concerning the displayed recordings.

Note: improper damping and calibration account for a large percentage of the errors in direct arterial blood pressure monitoring.

Complications of arterial lines:

- Haematoma.
- Bleeding.
- Disconnection: haemorrhage.
- Air emboli.

Rare complications:

- Site infection/abscess/sepsis.
- Thrombosis.
- Ischaemia/blanching of extremity.
- Nerve injury.
Observe for signs of cannula displacement:

- Swelling.
- Haematoma.
- Bleeding.
- Lack of a normal arterial waveform.
- Fluid leakage.
- Purulent discharge.
- Blanching or delayed capillary refill.
- Pain, discomfort, numbness or paraesthesia.
- Report any of the above to medical staff.

The cannula must be exposed and continually observed.
This is essential for patient safety and to minimise blood loss if equipment becomes disconnected.
The patient must not be left unattended.

Arterial blood gas sampling:

Accurate results for an arterial blood gas (ABG) depend on the proper manner of collecting, handling, and analysing the specimen. ABG measurements are particularly vulnerable to sampling errors and can produce incorrect blood results. It should be recognised that sampling is risky, prone to contamination and should only be done by appropriately trained and competent staff.

Sampling errors:

- Presence of air in the sample. Any air bubble in the sample must be expelled as soon as possible after withdrawing the sample and before mixing with heparin or before any cooling of the sample has been done.

- Inadequate removal of flush solution in arterial lines prior to blood collection. Staff should be aware of the volume of system dead-space. It is recommended that a volume 3 times the dead-space should be discarded to avoid contamination. This means that 2ml of fluid should be discarded when sampling from the distal 3-way tap.

- Collection of venous rather than arterial blood.

- Insufficient mixing of heparin in the syringe after blood is drawn. Avoid this by mixing the blood sample thoroughly be inverting the syringe up to 10 times and rolling it between the palms as shown above.

- A delay in specimen transportation/delayed analysis of a non-cooled sample: ABG samples may need to be sent to the labs/other ward areas on a few occasions (e.g. if unit blood gas machine is faulty). Samples that are sent to the lab or other ward areas should have the correct patient identification label and the sample should be transported in a bag of ice. Lab staff should be informed in advance of the ABG sample being sent.

- Missing or wrong patient/sample identification.

Additional points to consider:

- Staff should be mindful of iatrogenic anaemia particularly in the paediatric population.
- Staff should be vigilant when interpreting results. There should be a low threshold for repeat sampling.
- Blood sampling frequency should be kept to a minimum and only done when strictly necessary particularly in the critically ill Jehovah’s Witness.
Sampling from the arterial line:

Staff should always ask themselves “Do I need to take this sample?”

Indications include:

- Changes in monitored respiratory variables e.g. oxygen saturation or tidal volume.
- Monitoring of results of changes in ventilation.
- Monitoring of electrolytes/glucose.
- Monitoring of bleeding or coagulation tests.
- Monitoring acid/base abnormalities.

Equipment needed for obtaining ABG sample:

- Gloves.
- Heparinised blood gas syringe with cap.
- A 2ml or 5ml syringe.
- Alcohol swab.
- A sterile gauze swab.
- Red cap.

Procedure for obtaining an arterial blood gas sample:

Mute the alarm on the monitor.

1. Wash hands and apply gloves and apron.
2. Remove the red cap from the 3-way port and clean the port with the alcohol swab for 15 seconds.
3. Connect 2ml syringe to the hub. Turn the 3-way tap ON to the artery and OFF to the transducer.
4. Withdraw 2ml of blood or until the line is cleared off infusate.
5. Turn 3-way tap diagonally to close OFF artery, port and transducer.
6. Connect the blood gas syringe and withdraw blood slowly.
7. Turn 3-way tap OFF diagonally to the artery, port and transducer prior to removing the ABG syringe.
8. Turn 3-way tap ON to the transducer and artery and then squeeze the flush device actuator to clear the line completely of blood.
9. Turn 3-way tap ON to the port and the transducer and then flush the port clear of blood onto the piece of sterile gauze.
10. Replace with a clean red cap.
11. Turn 3-way tap on to transducer and artery.
12. Dispose of water materials, remove gloves and apron and decontaminate hands.
The arterial cannula should be removed if:

- Bacteraemia is noted/local sign of infection is noted: swab the site and send to microbiology.
- The extremity blanches/limb circulation is compromised.
- The cannula is misplaced or the arterial trace has been lost and/or unable to sample despite troubleshooting.
- It is no longer required for frequent monitoring and blood sampling.

Removing the arterial cannula:

- Perform hand hygiene and comply with infection control measures.
- Routine sending of cannula tips is not required. However, if the line is being removed for suspected infection retain the cannula tip and send to microbiology.
- Cut any retaining sutures and gently withdraw the cannula.
- Using a sterile gauze swab immediately apply pressure for up to 5 minutes or until bleeding has stopped.
- Apply a sterile dressing over the arterial puncture site.
- Observe the site regularly for bleeding or haematoma.

Problems with infusions and sampling from arterial lines:

Issue - arterial lines are routinely used in critical care areas for sampling arterial blood to measure blood gases, glucose and electrolytes. Patients may be harmed if the wrong infusion is given to keep the line open or when poor sampling leads to delayed or inappropriate treatment.

Reducing risks:

To minimise risks, clinical teams should ask themselves:

- Have I recorded the clinical reason for inserting this line? Is it clearly marked as an arterial line?
- Do I need to take this sample?
- Do I know how to do this safely (e.g. removing air from sample)?
- Have I picked the right infusion fluid bag? Did someone else check this?
- Can the fluid identity/label be seen, if pressure bags are used?
- Is the reading from the sample within the expected range? Could the sample have been contaminated?


- Sampling from arterial lines is risky and should only be done by trained, competent staff. Trusts should raise awareness of risks and review local guidelines. These should include criteria for requests for blood gas analysis; sampling technique; monitoring and interpretation of results (including unexpected results).
- Arterial infusion lines must be clearly identified. This means labelling or use of other safety solutions such as marked lines adopted by some trusts.
- The infusion solution (flush solution) must be prescribed and checked before administration. Further checks should be made at regular intervals and key points (such as shift handover).
- Staff should only use sodium chloride 0.9% to keep lines open.
- Labels should clearly identify contents of infusion bags, even when pressure bags are used. Over time, manufacturers should develop a universal system to address this problem.
Normal arterial waveform:

- Begins with a sharp rise.
- The sharp rise represents ejection of blood from the left ventricle.
- The rounded top represents systolic blood pressure.
- The force of contraction diminishes and the pressure drops.
- The slight upswing of the waveform is referred to as the dicrotic notch and represents closure of the aortic valve.
- The downward slope after the dicrotic notch is the lowest point in diastole.
- The area under the curve = MAP.

Waveform morphology will vary depending on the site of insertion:

The further away from the aorta:

- The taller the systolic peak.
- The further the dicrotic notch.
- The lower the end-diastolic pressure.
- The later the arrival of the pulse.

Abnormal arterial waveforms:

1. Aortic stenosis
2. Aortic regurgitation.
Abnormal arterial waveforms:

3. Left ventricular outflow tract obstruction.  
4. Hypertension and peripheral vascular disease.

“Damping” of the arterial line waveform:

- Anything that reduces energy in the transducer system will reduce the amplitude of the oscillations. This is termed “damping”.
- Some degree of damping is needed in all systems (‘critical damping’) but if excessive, the output will be adversely affected.
- Excessive damping is referred to as over-damping.
- Insufficient damping is referred to as under-damping.
- Most damping arises from friction in the fluid pathway.

The square wave test:

When the fast flush valve is squeezed, the transducer receives a surge of the pressurised saline. This produces a waveform that rises sharply, plateaus and drops off sharply when the flush valve is released again.

This is the “square wave”. The accurate, responsive adequately damped waveform is displayed.

A good arterial line trace has a distinct dicrotic notch, and after the fast flush test there are two oscillations only.
The over-damped arterial line waveform:

- The over-damped trace will lose its dicrotic notch, and there won’t be more than one oscillation.
- This happens when there is a clot in the catheter tip, or an air bubble in the tubing.
- Over-damping lowers the systolic pressure.

The under-damped arterial line waveform:

- The under-damped trace will overestimate the systolic pressure and there will be many post-flush oscillations.
- An under-damped trace is often characterised by a high initial spike in the waveform.
- The MAP remains the same in spite of damping.

Damping can be caused by:

- 3-way taps.
- Bubbles and clots.
- Vasospasm.
- Kinks in the cannula or tubing.
- Narrow, long or compliant tubing.
- Patient factors e.g. tachycardia, high cardiac output states.

Improper damping and calibration account for a large percentage of the errors in direct arterial pressure monitoring.
Blood pressure:

- Normal adult blood pressure range: from 100/60 mmHg to 140/90 mmHg.
- Systolic pressures vary between 100 and 140 mmHg.
- Diastolic pressures may range between 60 and 90 mmHg.
- A resting diastolic pressure persistently exceeding 90 mmHg would indicate hypertension.
- The mean arterial pressure is more crucial as it is the pressure/real ‘driving force’ which pushes blood through the systemic circulation.

Mean arterial pressure:

- MAP = \((\text{diastole} \times 2) + \text{systole} ÷ 3\).
- Defined as the average arterial blood pressure during a single cardiac cycle.
- Reflects haemodynamic perfusion pressure of the vital organs.
- A MAP of at least 60 mmHg is necessary to perfuse the coronary arteries, brain, and kidneys.
- Normal range is approx 70-110 mmHg.
- Aim for mean arterial pressure \(≥ 65\text{mmHg}\) (Surviving Sepsis Campaign Guidelines).

Some examples where monitoring MAP is especially important:

- Patients with septic shock receiving vasopressors.
- Acute cerebral injury.
- Cardiac patients receiving vasodilator (GTN) infusions.
- Patients presenting with dissecting abdominal aortic aneurysm.

Sepsis and early directed goal therapy:

- Maintain MAP \(≥ 65\text{mmHg}\).
- Sometimes fluid resuscitation alone may suffice.
- When an appropriate fluid challenge fails to restore an adequate arterial pressure and organ perfusion, therapy with vasopressors should be started ..... even when hypovolaemia has not resolved or when a fluid challenge is in progress.

Concerns regarding inappropriate or detrimental use of vasopressors:

- In the adequately volume-resuscitated patient, vasopressor use may worsen already inadequate organ perfusion.
- Debate continues as to whether vasopressor agents may raise blood pressure at the expense of the perfusion of vulnerable organs particularly, the kidneys and the gut.
- Possibility of over-enthusiastic use and targeting an unnecessarily high blood pressure may increase left ventricular work to an unsustainable degree and worsen cardiac output. This may be more harmful in patients with pre-existing heart disease.
# Preventing and Troubleshooting Arterial Line Problems

<table>
<thead>
<tr>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
</table>
| Haemorrhage or accidental removal of arterial line. | Loose connections and unstable security of arterial line are likely causes. Retaining sutures may not always be in place or adhesive strips may not be adequately securing the cannula to the skin. Immediately turn off the 3-way tap nearest the cannula and check the patient’s vital signs, then undertake the following:  
- Ensure all transducer connections are tight. Reconnect any detachments. Whilst the 3-way tap nearest the cannula remains in the ‘off’ position, remove the cap and using the flush device, flush the line to ensure that all air/clot is removed from the system.  
- If retaining sutures are loose, inform medical staff. Alternatively, use iv tegaderm dressing & use the adhesive strips to secure the ‘wings’ of the arterial cannula to the skin.  
- If the arterial cannula is not secured with sutures, use iv tegaderm dressing and use the adhesive strips to secure the ‘wings’ of the arterial cannula to the skin. Highlight in the alert box on the observation chart “ARTERIAL LINE NOT STITCHED”.  
- Where possible, the cannula site (limb) should be exposed and continuously observed.  
- Ensure arterial monitor alarm is on so that any accidental disconnection can be dealt with quickly.  
- If arterial line is removed: apply firm pressure to the puncture site for at least 5 minutes or until bleeding has stopped. |
| Blanching of affected limb with arterial cannula in situ. |  
- Immediately inform medical staff as this may indicate arterial occlusion.  
- Assessment should include checking for adequate circulation to the cannulated limb, inspecting skin colour, palpation of skin temperature and assessment of capillary refill time and distal pulses if appropriate.  
- Medical staff may request to remove the arterial line and an alternative site selected for replacement. |
| Potential for drug administration errors. |  
- Drugs must **never** be administered via arterial lines as even small doses can cause severe toxicity.  
- The arterial line should be clearly identified by using red caps and label accordingly.  
- Transducer infusion solution: this must always be 0.9% sodium chloride. Check the infusion solution against the fluid prescription and obtain witness countersignature. |
| Unable to aspirate cannula when undertaking blood sampling. |  
- Check arterial cannula for any kinks/incorrect position of the 3-way tap.  
- Apply gentle traction to the cannula.  
- Gently try to flush. Inform medical staff if unable to flush.  
- Arterial cannula may need to be replaced. |
## Preventing and Troubleshooting Arterial Line Problems

<table>
<thead>
<tr>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
</table>
| Potential for insertion site problems: redness, swelling, leakage.     | • Report any concerns to medical staff and document.  
• Ensure adequate hand hygiene and always use gloves when handling arterial line.  
• If evidence of redness/inflammation or exudate: obtain wound swab and send to microbiology.  
• If the arterial catheter is removed for suspected infection: the distal tip of the catheter should be sent to microbiology. Record on appropriate documentation. |
| Loss of waveform                                                       | • The arterial catheter may have migrated against vessel wall: the waveform may be restored by repositioning the affected limb.  
• Arterial catheter may be kinked: dressing may need to be removed to allow inspection at the insertion site.  
• Baxter arterial cannula with flow-switch: check that the flow-switch is not in closed/locked position.  
• Check the transducer set: roller clamps should be open and 3-way taps should not be turned off. Check the transducer set for any kinks.  
• Sensor cable: check sensor cable has a secure connection to the transducer base.  
• Pressure infusor may have lost it inflation pressure: check inflation pressure and maintain inflation at 300mmHg.  
• Check volume remaining of infusion solution inside the pressure infusor: never allow the infusion solution to empty. Failure to replace the infusion solution means that the cannula will not receive any flush to maintain its patency and risk complete occlusion. Ensure adequate ambient lighting to inspect the flush system particularly during night time hours or where lighting is reduced.  
• Possible clot formation at the end of the arterial cannula: insert a syringe into the 3-way tap and gently aspirate to aid release of clot. Flush the line once the clot has been removed.  
• Inaccurate readings or falsely high readings may be due to: incorrect placement of transducer, kinks, air bubbles or clots.  
• Perform calibration/zeroing procedure.                                |
| Abnormal waveform.                                                     |                                                                                                                                                                                                          |
| Dampened waveform.                                                     |                                                                                                                                                                                                          |
| Inaccurate readings.                                                   |                                                                                                                                                                                                          |
| Difficulty with zeroing.                                               | • Check all equipment and connections between patient and monitor. Check that the sensor cable is securely connected to the transducer base.  
• Ensure all roller clamps are open and 3-way taps are in correct position.  
• Check system for air bubbles and clots.  
• Perform recalibration/zeroing procedure.                              |
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 PaO2 should be > 10kPa on air and about 10kPa less than the % inspired concentration.

3. Determine the pH or H+ concentration:
   - Is the patient acidaemic: pH < 7.35
   - Is the patient alkalaemic: pH > 7.45

4. Determine the respiratory component:
   - PaCO2 > 6.0 kPa: respiratory acidosis (or respiratory compensation for a metabolic alkalosis).
   - PaCO2 < 4.7 kPa: respiratory alkalosis (or respiratory compensation for a metabolic acidosis).

5. Determine the metabolic component:
   - HCO3 < 22 mmol/L: metabolic acidosis (or renal compensation for a respiratory alkalosis).
   - HCO3 > 26 mmol/L: metabolic alkalosis (or renal compensation for a respiratory acidosis).

Some clinicians prefer to use the base excess (or deficit) instead of the HCO3. 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 +/- 2mmol/L.

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.
Initial information: A 21 year old woman is thrown from her horse at a local event. On the way to hospital she has become increasingly drowsy and the paramedics have inserted an oropharyngeal airway and given her high flow oxygen via a face-mask. An arterial blood gas sample has been taken and reveals the following:

Inspired oxygen: 40% (FiO2 0.4)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2</td>
<td>18.8kPa</td>
<td>&gt; 10kPa on air</td>
</tr>
<tr>
<td>pH</td>
<td>7.19</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>10.2kPa</td>
<td>4.7 – 6.0 kPa</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>23.6 mmol/L</td>
<td>22 – 26 mmol/L</td>
</tr>
<tr>
<td>Base excess</td>
<td>-2.4 mmol/L</td>
<td>+/-2 mmol/L</td>
</tr>
</tbody>
</table>

Use the 5-step approach to guide interpretation of the results:

Step 1: How is the patient?
- The reduced level of consciousness and obstructed airway will impair oxygenation and ventilation, causing an increased PaCO2, a respiratory acidosis. There is unlikely to be much compensation (change in bicarbonate) because of the acuteness of the situation.

Step 2: Assess oxygenation:
- The PaO2 should be about 10kPa less than the % inspired concentration. In this patient the gradient is increased suggesting impaired oxygenation.

Step 3: Determine status of the pH:
- The patient is acidaemic: pH < 7.35.

Step 4: Determine the respiratory component:
- The pH < 7.35, but the HCO3 is within normal limits, indicating no metabolic disturbance or compensation.

Step 5: Determine metabolic component:
- The pH < 7.35, but the HCO3 is within normal limits, indicating no metabolic disturbance or compensation.

In summary: an acute respiratory acidosis with impaired oxygenation.

Treatment will include:

Improving the airway and ventilation to reduce the PaCO2, particularly as the patient may have a significant head injury.
Arterial blood gas analysis workshop: Case study 2

Initial information: a 65 year old man with severe COPD has been found collapsed in the respiratory unit. On initial assessment by the ward nurse he is apnoeic but has an easily palpable carotid pulse. The nurse is attempting to ventilate his lungs with a bag-mask and supplemental oxygen (with reservoir) and has called the arrest team.

On arrival:
- Oropharyngeal airway, ventilated with bag-mask, oxygen at 15 litres/min.
- Carotid pulse palpable, 90/min; O2 sats 99%.
- Comatose (GCS 3).

Arterial blood gas reveals:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspired oxygen</td>
<td>85% (FiO2 0.85) estimated</td>
<td></td>
</tr>
<tr>
<td>PaO2</td>
<td>19.5kPa</td>
<td>&gt; 10kPa on air</td>
</tr>
<tr>
<td>pH</td>
<td>7.10</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>18.0 kPa</td>
<td>4.7 – 6.0 kPa</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>36.0 mmol/L</td>
<td>22 – 26 mmol/L</td>
</tr>
<tr>
<td>Base excess</td>
<td>+12.0 mmol/L</td>
<td>+/-2 mmol/L</td>
</tr>
</tbody>
</table>

Use the 5-step approach to guide interpretation of the results:

Step 1: How is the patient?
From the history we would predict pre-existing COPD to cause impaired oxygenation and a chronically increased PaCO2. The period of apnoea will have further increased this PaCO2, causing a respiratory acidosis and a low pH. There will be increased bicarbonate (positive base excess) due to COPD.

Step 2: Assess oxygenation:
The patient is not hypoxic, but there is significant impairment of oxygenation as indicated by the gradient between inspired oxygen and PaO2.

Step 3: Determine status of the pH:
The patient is acidaemic: pH < 7.35.

Step 4: Determine the respiratory component:
The pH < 7.35, and the PaCO2 > 6.0kPa indicating a respiratory acidosis.

Step 5: Determine metabolic component:
The pH < 7.35, and the HCO3 and base excess are both significantly increased indicating a compensatory metabolic alkalosis, reflecting the chronically raised PaCO2 consistent with COPD.

In summary: the significant acidaemia (pH 7.10) indicates an additional acute respiratory acidosis as a result of the respiratory arrest. In the pre-existing compensated chronic respiratory acidosis, the pH would have been close to normal.

Treatment will include: If appropriate, non-invasive ventilation or tracheal intubation and ventilation.
**Arterial blood gas analysis workshop: Case study 3**

Initial information: A 60 year old man is brought to the emergency department after a witnessed out-of-hospital cardiac arrest. The paramedics arrive after 7 minutes, during which CPR has not been attempted. His initial rhythm was VF and the paramedics subsequently restored a spontaneous circulation after the 3rd shock.

**On arrival:**
- Intubated and ventilated with 50% oxygen.
- Pulse 120/min; BP 150/95 mmHg.
- Comatose (GCS 3)

**Arterial blood gas reveals:**

Inspired oxygen: 50% (FiO2 0.5)  
PaO2 7.5kPa  
pH 7.10  
PaCO2 6.2kPa  
Bicarbonate 14.0 mmol/L  
Base excess -10.0 mmol/L

**Use the 5-step approach to guide interpretation of the results:**

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

From the history we would predict that oxygenation may be impaired if he has aspirated or has pulmonary oedema. During the arrest anaerobic respiration would lead to accumulation of lactate causing an acidaemia (low pH) and a low bicarbonate (negative base excess) as this is consumed but not replaced. Apnoea would initially have increased his CO2, causing a respiratory acidosis, but this may now be corrected as he is now intubated and ventilated.

**Step 2: Assess oxygenation:**

The patient is hypoxic, PaO2 7.5kPa, and the gradient between inspired oxygen and PaO2 is increased indicating impaired oxygenation.

**Step 3: Determine status of the pH:**

The patient is acidaemic; pH <7.35.

**Step 4: Determine the respiratory component:**

pH < 7.35, and PaCO2 > 6.0kPa indicating respiratory acidosis. This is only minimal as a result of being ventilated.

**Step 5: Determine metabolic component:**

The pH < 7.35, and the HCO3 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 a mixed metabolic and respiratory acidosis – the predominant component is metabolic, with significant impairment of oxygenation.

**Treatment will include:**

- Increase the FiO2 – this should increase the PaO2.
- Increase the minute ventilation to reduce the PaCO2 – 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.
Arterial blood gas analysis workshop: Case study 4

Initial information: a 75 year old woman is admitted to the ED following a VF cardiac arrest, witnessed by paramedics. This had been preceded by 30 min of severe central chest pain. Spontaneous circulation is restored after 2 shocks, but the patient remained apnoeic and unresponsive. The paramedics intubated her trachea and ventilated her with an automatic ventilator.

On arrival:
- Tube confirmed in trachea; tidal volume 900ml, rate 18/min; 100% oxygen.
- Pulse 100/min; BP 90/54 mmHg.
- Comatose (GCS 3).

Arterial blood gas reveals:

Inspired oxygen: 50% (FiO2 0.5)  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2</td>
<td>25.4 kPa</td>
<td>&gt; 10kPa on air</td>
</tr>
<tr>
<td>pH</td>
<td>7.62</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>2.65 kPa</td>
<td>4.7 – 6.0 kPa</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>20.0 mmol/L</td>
<td>22 – 26 mmol/L</td>
</tr>
<tr>
<td>Base excess</td>
<td>-4.0 mmol/L</td>
<td>+/-2 mmol/L</td>
</tr>
</tbody>
</table>

Use the 5-step approach to guide interpretation of the results:

Step 1: How is the patient?
From the history we would predict possible impairment of oxygenation, a reduced PaCO2 due to the high minute volume causing a respiratory alkalosis and increased pH. There will probably be minimal metabolic disturbance due to brief period of the arrest, with possibly a slightly reduced bicarbonate and base excess.

Step 2: Assess oxygenation:
The patient is well oxygenated, but there is a significant gradient suggesting impaired oxygenation; this would fit with aspiration or pulmonary oedema.

Step 3: Determine status of the pH:
The patient is alkalaemic; pH > 7.45.

Step 4: Determine the respiratory component:
The PaCO2 < 4.7 kPa indicating a respiratory alkalosis.

Step 5: Determine metabolic component:
The HCO3 and base excess are both slightly decreased reflecting a minor metabolic acidosis secondary to the period of chest pain during which cardiac output is likely to have been impaired and the subsequent brief cardiac arrest. There will also be a small contribution from the acute lowering of the PaCO2.

In summary: a respiratory alkalosis, mild metabolic alkalosis and impaired oxygenation.

Treatment will include:
- Reduction of the FiO2; aim for PaO2 12 kPa.
- Reduce the minute volume; set a volume of 500ml and a rate of 10-12 breaths/min. Further adjustments may be required depending on the results of repeat ABGs.
**Arterial blood gas analysis workshop: Case study 5**

Initial information: an 18 year old insulin dependent diabetic is admitted to the emergency department. He has been vomiting for 48 hours and because he was unable to eat, he has taken no insulin.

**On arrival:**

- Breathing spontaneously RR 35/min; oxygen 4L/min via Hudson mask, O2 sats 98%.
- Pulse 130/min; BP 90/65 mmHg.
- GCS 12 (E3, M5, V4).

**Arterial blood gas reveals:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspired oxygen</td>
<td>30% (FiO2 0.3)</td>
<td></td>
</tr>
<tr>
<td>PaO2</td>
<td>17.0 kPa</td>
<td>&gt; 10kPa on air</td>
</tr>
<tr>
<td>pH</td>
<td>6.89</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>2.48 kPa</td>
<td>4.7 – 6.0 kPa</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>4.7 mmol/L</td>
<td>22 – 26 mmol/L</td>
</tr>
<tr>
<td>Base excess</td>
<td>-29.2 mmol/L</td>
<td>+/-2 mmol/L</td>
</tr>
</tbody>
</table>

**Use the 5-step approach to guide interpretation of the results:**

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

From the history we would predict developing ketoacidosis or metabolic acidosis with a low pH, and as a result low bicarbonate (negative base excess) as being consumed to buffer the acids produced, but not fully replaced by the kidneys. The hyperventilation is an attempt to lower his CO2 causing a compensatory respiratory alkalosis. If no signs in his chest, relatively normal oxygenation.

**Step 2: Assess oxygenation:**

The patient is well oxygenated, with minimal evidence of any impaired oxygenation.

**Step 3: Determine status of the pH:**

The patient is profoundly acidaemic; pH <7.35.

**Step 4: Determine the respiratory component:**

The PaCO2 < 4.7 kPa indicating a respiratory alkalosis.

**Step 5: Determine metabolic component:**

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

**In summary:** 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. There is primary metabolic acidosis with partial compensation provided by the respiratory alkalosis.

**Treatment would include:**

- Fluid resuscitation – initially with normal saline.
- Insulin – with regular measurement of blood glucose.
- The use of bicarbonate is controversial but many clinicians would give it in the presence of such a severe acidaemia, particularly if it did not improve rapidly after starting the above measures.
Arterial blood gas analysis workshop: Case study 6

Initial information: a 75 year old man is on the surgical ward 2 days after a laparotomy for a perforated sigmoid colon secondary to diverticular disease. He has become increasingly hypotensive over the last 6 hours, despite 1000ml 0.9% saline.

On arrival:
- RR 35/min; O2 Sats 92% on 6 litres O2/min via facemask.
- Pulse 120/min; sinus tachycardia; warm peripheries; BP 70/40 mmHg.
- Urine output 90ml in the last 6 hours.
- GCS 13 (E3, M6, V4).

Arterial blood gas reveals:

Inspired oxygen: 40% (FiO2 0.4) estimated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Normal values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2 8.2 kPa</td>
<td></td>
<td>&gt; 10kPa on air</td>
</tr>
<tr>
<td>pH 7.17</td>
<td></td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>PaCO2 4.5 kPa</td>
<td></td>
<td>4.7 – 6.0 kPa</td>
</tr>
<tr>
<td>Bicarbonate 12 mmol/L</td>
<td></td>
<td>22 – 26 mmol/L</td>
</tr>
<tr>
<td>Base excess -15 mmol/L</td>
<td></td>
<td>+/-2 mmol/L</td>
</tr>
</tbody>
</table>

Use the 5-step approach to guide interpretation of the results:

Step 1: How is the patient?
From the history we would predict a metabolic acidosis from sepsis, with a reduced pH and a low bicarbonate, (negative base excess). His PaCO2 will be low from hyperventilation, causing a compensatory respiratory alkalosis. Oxygenation will be impaired as his O2 sats are reduced.

Step 2: Assess oxygenation:
The patient is hypoxic with evidence of any impaired oxygenation.

Step 3: Determine status of the pH:
The patient is profoundly acidaemic; pH <7.35.

Step 4: Determine the respiratory component:
The PaCO2 < 4.7 kPa indicating a mild respiratory alkalosis.

Step 5: Determine metabolic component:
The HCO3 and base excess are both significantly reduced indicating a severe metabolic acidosis.

In summary: there is a primary metabolic acidosis with slight compensation provided by the mild respiratory alkalosis. The degree of this is probably limited by the presence of an acute abdomen. The most likely diagnosis is sepsis syndrome secondary to intra-abdominal infection. The plasma lactate would be elevated.

Treatment would include:
- Increase FiO2.
- Start fluid resuscitation.
- Call for help from rapid response team (critical care outreach team).
- Start antibiotics.
The significance of measuring and monitoring lactate in the critically ill patient:

Normal range: 0.63 – 2.44mmol/L.

- Lactate acid is an intermediate product of carbohydrate metabolism and is derived from muscle cells and red blood cells.
- During exercise, lactate levels may increase.
- However, the liver can normally metabolise more lactate than is produced and can return lactate levels to normal within a few hours.
- Elevated levels of lactate tend to lower pH with consequent disturbance of metabolism/protein structure, and beyond a tolerance level results in muscle fatigue or ‘cramp’.

Why should it be considered in critically ill patients?

- Hyperlactaemia is typically present in patients with severe sepsis or septic shock and may be secondary to anaerobic metabolism due to hypoperfusion.
- The prognostic value of raised blood lactate levels has been well established in septic shock patients, particularly if the high levels persist.
- Therefore obtaining serum lactate may be considered essential to identifying tissue hypo-perfusion in patients who are not yet hypotensive but who are at risk for septic shock.
- It is important to recognise that severe oxygen deprivation of tissue results in a switch from aerobic to anaerobic metabolism.
- Because lactate is the main product of anaerobic metabolism, it accumulates when there is oxygen deprivation.
- Its concentration increases when its production by ischaemic tissue overwhelms its elimination by the liver and kidneys.
- Hypoxia, seen in shock, congestive heart failure, (or any other condition that would cause problems in oxygen being picked up or transported in the blood), hepatic dysfunction, ischaemia and pulmonary insufficiency are all associated with increased serum lactate.
- Resuscitation of hypo-perfused patients should be considered complete only when there is no evidence of ongoing anaerobic metabolism or tissue acidosis.

To be completed within 3 hours:

1. Measure lactate level.
2. Obtain blood cultures prior to administration of antibiotics.
3. Administer broad spectrum antibiotics.
4. Administer 30ml/kg crystalloid for hypotension or lactate ≥ 4mmol/L.

To be completed within 6 hours:

5. Apply vasopressors (for hypotension that does not respond to initial fluid resuscitation) to maintain a MAP ≥ 65mmHg.
6. In the event of persistent hypotension despite volume resuscitation or initial lactate ≥ 4mmol/L:
   - Measure CVP and target ≥ 8 mmHg.
   - Measure central venous oxygen saturation (ScvO2) and target ≥ 70%.
7. Re-measure lactate if initial lactate was elevated and aim for normalisation.