Arterial & Venous Blood Gas Sampling Study Guide

Clinical Skills Teaching & Learning Centre
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## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>A-a gradient</td>
<td>Alveolar- arterial gradient</td>
</tr>
<tr>
<td>ABG</td>
<td>Arterial blood gas</td>
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<tr>
<td>Acidaemia</td>
<td>The state used to describe a patient with a low blood pH</td>
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<tr>
<td>Acidosis</td>
<td>The process leading to acidaemia</td>
</tr>
<tr>
<td>Alkalaemia</td>
<td>The state used to describe a patient with a raised blood pH</td>
</tr>
<tr>
<td>Alkalosis</td>
<td>The process leading to alkalaemia</td>
</tr>
<tr>
<td>ANTT</td>
<td>Aseptic non touch technique</td>
</tr>
<tr>
<td>Arteriospasm</td>
<td>Spasm of an artery</td>
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<tr>
<td>BE</td>
<td>Base excess</td>
</tr>
<tr>
<td>Buffer</td>
<td>A solution which aims to keep the pH at a nearly constant value</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Disease</td>
</tr>
<tr>
<td>Collateral circulation</td>
<td>The alternate circulation around a blocked artery or vein via another path</td>
</tr>
<tr>
<td>Cyanosis</td>
<td>Bluish colouration of the skin, often due to inadequate oxygenation</td>
</tr>
<tr>
<td>FiO₂</td>
<td>Fraction of inspired oxygen</td>
</tr>
<tr>
<td>H⁺</td>
<td>Hydrogen ion</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>The bicarbonate ion</td>
</tr>
<tr>
<td>Homeostasis</td>
<td>A system that regulates the environment to maintain a stable constant state</td>
</tr>
<tr>
<td>Hypercapnia</td>
<td>A patient who has raised CO₂ levels</td>
</tr>
<tr>
<td>Hypercarbia</td>
<td>A patient who has raised CO₂ levels</td>
</tr>
<tr>
<td>Hypoxaemia</td>
<td>A condition where the blood is deficient of oxygen</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>A condition where the body or a specific part of the body is deprived of Oxygen</td>
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<tr>
<td>NIV</td>
<td>Non-Invasive Ventilation</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>The partial pressure of carbon dioxide</td>
</tr>
<tr>
<td>PaO₂</td>
<td>The partial pressure of arterial oxygen</td>
</tr>
<tr>
<td>PAO₂</td>
<td>Partial pressure of alveolar oxygen</td>
</tr>
<tr>
<td>pH</td>
<td>The acidity/ alkalinity of the blood</td>
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<tr>
<td>RCUK</td>
<td>Resuscitation Council UK</td>
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<tr>
<td>Rubefacient cream</td>
<td>A topical cream that causes dilation of the capillaries and an increase in blood circulation</td>
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<tr>
<td>VBG</td>
<td>Venous blood gas</td>
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Learning Objectives

Year 3

- To understand what an arterial blood gas (ABG) and a venous blood gas (VBG) test are
- To be able to recognise the indications and contraindications for blood sampling
- To understand how to perform ABG sampling (from the radial artery) safely using ANTT principle
- To have an awareness of how to recognise, interpret and report abnormal results
- To have an awareness of the difference between ABG and VBG interpretation
Introduction

This study guide will look at taking and analysing an arterial blood gas sample and comparing this with a venous blood gas sample.

There are variations in practice throughout different clinical sites and you must ensure you are familiar with, and follow, local Trust policy and procedure when in clinical practice.

Before you take an ABG, you should consider the patient, there are several reasons why an ABG may be indicated. ABGs are often taken routinely for acutely unwell patients, and you may need to initially assess the patient using an ABCDE approach. Alternatively, venous gases may be taken depending on the patient’s condition, please ensure that this is taken into consideration before attempting to interpret the result (please see interpretation).

Try to ensure that you have enough relevant clinical information about the patient, including any recent observations, full renal profile, full blood count, blood glucose and any other relevant blood results. You will also need to know the patient’s temperature and the amount of oxygen that they are inspiring prior to analysing the sample. All of the above can be used to aid diagnosis, or aid and/or monitor treatment in conjunction with the ABG result.

What is Arterial Blood Gas (ABG) sampling?
This is a procedure of taking a sample of arterial blood for analysis to look at the amount of certain gases dissolved in the arterial blood.

This is a direct vascular puncture usually performed on the radial artery, although you may see the brachial or femoral artery used in practice.

The information on ABGs in this study guide and in the teaching presentation relate to radial artery puncture only, unless specifically stated.

What is Arterial Blood Gas (ABG) analysis?
Analysis of the ABG sample will examine the pH of the patient’s blood along with the amount of oxygen, carbon dioxide and bicarbonate. Many areas also have the ability to examine the blood further by also testing for concentrations of lactate, electrolytes and or haemoglobin.

Arterial blood gases (ABGs) are an important routine investigation to monitor the acid-base balance of patients, and they may help make a diagnosis. They can also indicate the severity of a condition and help to assess/monitor and/or guide treatment.
What does the ABG test?
Listed below are the main components tested in an ABG;

- **PaO₂** - *The partial pressure of oxygen* in the arterial blood, measured in kPa or mmHg (kPa will be used in this guide), allowing staff to check if the patient is being sufficiently oxygenated.
- **pH** - *the acidity/alkalinity* of the blood.
- **PaCO₂** - *The partial pressure of carbon dioxide* in arterial blood measured in kPa or mmHg, which can indicate to staff the efficacy of the patient’s ventilation.
- **HCO₃⁻** - *The bicarbonate ion* is calculated in mEq/L. The HCO₃⁻ is used when assessing the metabolic component of acid-base disorders.
  - **BE** - *Base excess* is calculated in mmol/L. The base excess is used when assessing the metabolic component of acid-base disorders. Contrasted with the bicarbonate levels, the base excess is a calculated value intended to completely isolate the non-respiratory portion of the pH change. A deviation from normal range is normally mirrored by a deviation in bicarbonate.

Different analysers can also perform additional tests, some of these are listed below;

- Lactate
- Magnesium
- Haemoglobin (Hb)
- Calcium
- Potassium
- Blood glucose

**Normal Ranges:**

<table>
<thead>
<tr>
<th>ABG Normal limits (Resuscitation Council UK 2016)</th>
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<tbody>
<tr>
<td><strong>Value</strong></td>
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<tr>
<td>PaO₂</td>
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<tr>
<td>pH</td>
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<tr>
<td>PaCO₂</td>
</tr>
<tr>
<td>HCO₃⁻</td>
</tr>
<tr>
<td>BE</td>
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</tbody>
</table>
Indications for taking an ABG
Arterial blood gases (ABGs) are an important routine investigation to monitor the acid-base balance of patients.

They can indicate the severity of a condition and help to assess/monitor/guide and/or monitor response to treatment. For example patients:

- With suspected sepsis
- Who are acutely unwell
- With exacerbation of asthma/COPD/hypercapnia
- With cyanosis
- With pancreatitis
- With diabetic ketoacidosis
- Where there is a suspicion of carbon monoxide poisoning.
Relevant Physiology

Biochemistry of ABG

Carbonic Acid Equation

This equation is the basis for the acid/base regulation of the body;

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

Bicarbonate (HCO₃⁻) and Hydrogen (H⁺) are produced from the dissociation of carbonic acid (H₂CO₃), which is a result of a reaction from carbon dioxide (CO₂) and water (H₂O).

Increased carbon dioxide would shift the balance on this equation to the right, therefore there would be more Hydrogen ions increasing acidity and reducing the pH.

From this you can understand that the more carbon dioxide a patient has in the body the more acidic the blood will be.

There are further equations when calculating the ABG and pH. The Henderson-Hasselbalch equation is used to calculate the hydrogen ion concentration, and therefore the pH can be calculated. The slightly simpler Kassirer-Bleich equation is a modification of the Henderson-Hasselbalch which is used to calculate the H⁺ and bicarbonate concentration and pH. More information about both of these equations is in the bibliography and further reading section of this study guide.

All of these equations can be difficult to use at the bedside, but the equations represent a very important relationship. They predict that the ratio of dissolved CO₂ to HCO₃⁻, determine H⁺ concentration and consequently pH.

A drop or rise in PaCO₂ will result in a drop or rise in H⁺ respectively, this allows us to determine if the abnormal pH has a respiratory cause, for example a rise in H⁺ in conjunction with a raised CO₂, will result in a lower pH, (and if the HCO₃⁻ is normal) this is called a respiratory acidosis.

HCO₃⁻ on the other hand, is inversely related to H⁺ concentration, a drop in bicarbonate levels will result in an increase in H⁺ concentration while a rise in bicarbonate levels result in a reduction in H⁺ concentration. Therefore when interpreting you can determine if the abnormal pH has a metabolic cause.

This buffer system is of physiological importance because both the respiratory and renal mechanisms for regulating pH work by adjusting this ratio.
Surface Anatomy

There are 3 key vessels to be aware of when performing an arterial puncture on the arm; the radial, brachial and ulna artery.

You should be able to identify all 3 vessels on your patient.
- The radial is where ABG’s are commonly performed, and where you will be performing an arterial stab.
- You may also see the brachial being used in clinical practice by senior clinicians
- When performing a radial ABG you will need to identify the ulna artery in order to assess the patient’s collateral circulation.

Arterial anatomy of the lower arm

![Arterial anatomy diagram](Figure 1)

![Arterial anatomy diagram](Figure 2)

For a recap on venous anatomy please also refer to venepuncture study guide.
Preparation

ANTT
Taking a VBG or an ABG should utilise an aseptic non touch technique (ANTT) approach
ANTT is practiced when carrying out invasive clinical procedures, such as taking blood gases. The key parts that should not be contaminated are the syringe tip, needle, patient’s skin and needle insertion site (ANTT, 2018).

Sharps Injury
If you sustain a needle stick, see Appendix 1.

There will be a policy in the Trust that you are working in and the School of Medicine has a Health and Safety code of practice available on the School’s Intranet.

You will need to complete an incident report form and inform the School of Medicine by emailing the Departmental Safety Coordinator: Dr Emma Beddoes, email: ebeddoes@liv.ac.uk
In order to reduce sharps injury, be aware of HSE regulations (2013).

Incorrect disposal of sharps may cause injury or death
Patient Safety

- Introduce yourself
- Check the patient’s identity and allergies
- Explain what you want to do
- Gain informed consent
- Consider an appropriate chaperone
- Adequate exposure maintaining dignity
- Position the patient appropriately – consider moving and handling
- Wear Personal Protective Equipment as required.
- Wash your hands before and after you touch the patient (as per WHO guidelines)

On first meeting a patient introduce yourself, confirm that you have the correct patient with the name and date of birth, if available please check this with the name band and written documentation such as the request form and the NHS/ hospital number/ first line of address. Some Trusts may have electronic ordering, please check your Trust. Check the patient’s allergy status, being aware of the skin preparation and if it is trust policy to infiltrate lignocaine first (for 5th years only).

Ensure the procedure is explained to the patient in terms that they understand, gain informed consent and ensure that you are supervised, with a chaperone available as appropriate. Allow the patient to ask any questions that they may have and discuss any past problems (e.g. fainting/bleeding/ anti-coagulant medication history).

Assist patient into a comfortable position, with arm supported. Position the patient’s arm with a dorsi-flexed wrist, you could use a pillow or a colleague to support the wrist.

![Image](image.png)

*Figure 3*

If the patient has a history of fainting, they may be positioned better on a trolley, ask the relatives if they have any problems with needles. Also consider the patient’s own personal preference (e.g. choice of arm) or issues preventing the use of an arm, eg; lymphoedema.

Don personal protective equipment, apron and gloves should be a minimum as you are coming into contact with bodily fluids (Loveday 2014), some Trusts recommend sterile glove use, please follow local policy and use sharps in accordance with HSE (2013).

Be aware of hand hygiene and preventing the spread of disease, WHO (2009), continue to use the modified Ayeliffe technique.

Do not remove Oxygen to take or assess ABG’s, this potentially can cause profound hypoxaemia.
Contraindications and Complications

Contraindications for using the radial artery

Do not perform the procedure on that arm if:

- The Allen’s test is negative, (page 14).
- The patient has an arterio-venous shunt/ fistula.
- There is underlying skeletal trauma.
- There is infection at the puncture site.

Use caution if:

- The patient is on anti-coagulation therapy.
- They have a history of clotting or bleeding disorder.
- The patient has known peripheral vascular disease in which case ensure that you perform the procedure under direct supervision from a senior clinician.

Complications of ABG sampling

Some complications that can occur following ABG sampling;

- Thrombus
- Neurological damage
- Faint/ vaso-vagal
- Arteriospasm
- Pain
- Haematoma
- Haemorrhage
- Infection
- Distal ischaemia
- Air embolism
- Sharps injury to staff
- Necrosis leading to potential amputation

Please consider whether the patient is suitable to have this procedure performed.
Modified Allen’s test for ABG sampling
Radial arterial puncture is contraindicated when there is a known deficiency of collateral circulation to the distal upper extremity.

A Modified Allen Test can be performed to assess the adequacy of the collateral circulation of the radial artery by the ulnar artery. It is recommended that this test be performed prior to sampling.

To perform the test:

1. Instruct the patient to make a fist to force the blood from the hand; this should be done for approximately 30 seconds.

2. Occlude both the ulnar and radial arteries.

3. Then instruct the patient to unclench the fist. The patient’s palm should appear blanched or pale.

4. Now, release pressure only from the ulnar artery. Adequate collateral circulation is indicated by the return of normal colour within 10 seconds (Ruengsakulrach et al 2001).

The test is classed as positive if collateral circulation is present, and this should be documented accordingly. If the test is negative you should not be continuing with the procedure on that limb and you should inform your supervisor.
Equipment for ABG

Try to minimise the spread of infection and follow ANTT principles; clean the tray, do not contaminate key parts by placing unsheathed needle in the tray.

If you are doing an ABG, consider:

- Sharps bin and tray
- Wipes for tray
- Hand gel
- ABG safety syringe, with filter
- Apron
- Skin preparation, preferably Chlorhexidine Gluconate 2%
- Sterile gauze
- Adhesive tape
- Sterile gloves

Syringe

A blood gas syringe must be used as it is usually heparinised to prevent coagulation, some syringes are pre-set and self-fill, and most have safety needles.

Please check the manufacturer's instructions prior to carrying out the procedure. The syringe to the left needs gentle pressure to ensure that the needle is fixed before removal of the lid, it is self-filling, but the plunger should be moved to you preferred fill line amount. It also comes with a filter cap (Fig. 14).
Procedure

Sequence of procedure for ABG is dependent on Trust policy, and is done after gaining informed consent and patient safety checks:

1. Clean tray
2. Wash hands
3. Prepare equipment, including checking expiry dates
4. Don Personal Protective Equipment
5. Clean skin
6. If lignocaine has been used allow it time to work
7. Perform procedure
8. Apply sterile gauze to the insertion site and apply pressure
9. Activate needle safe
10. Dispose of sharps immediately into the sharps bin
11. Use filter cap to expel air from the syringe and gently roll syringe.
12. Label bottle and send to the laboratory
13. Document procedure

Procedure for ABG

5. Clean skin- The product is Trust dependent, ChloraPrep® (containing Chlorhexidine Gluconate 2%) should be applied for 30 seconds and then given 30 seconds to dry as per manufacturer’s instructions. Do ensure the skin is dry before commencing procedure.
   - This may be done before gloves are applied.
   - ANTT suggests that the skin should not be repalpated after cleaning, otherwise sterile gloves should be worn- please refer to individual trust policy

6. Lignocaine- This cannot be infiltrated by student doctors until 5th year, please ensure that it has had time to work if used.

   Some patients can find this procedure to be extremely painful, so warn patients accordingly if infiltrated lignocaine has not been given prior to the procedure.
7. Find the pulsating radial artery then:
   - Hold the needle like a pen/ dart (different people will develop different techniques)
   - Slowly insert the needle into the radial artery maintaining an angle of 45 degrees.
   - On most patients the needle should not be advanced more than 4-6mm (caution with peripheral swelling/obesity)
   - Self-filling syringes will allow blood to flow into the syringe
   - If you are palpating the artery once the syringe is filling, gently release the pressure on the artery otherwise it can occlude and you will not get the sample
   - Obtain 1-2mls blood

8. Remove the needle
   - Immediately apply pressure to the puncture site with gauze.
   - Pressure should be applied for at least 5 minutes and caution should be taken with any patients on anti-coagulants.

9. Activate the needle safe device as appropriate

10. Dispose of the needle
    - Immediately into the sharps bin.

11. Gently roll the sample to ensure that the blood and heparin are mixed.
    - Consider use of filter cap (Fig 14) if available to expel air, otherwise use a cap (Fig 15).

12. Send the sample (with/without ice) straight to the lab or the analyser- depending on where you are working.
Documentation

Label the sample, this depends on where it is analysed, some may require a patient’s addressograph label, some may have stickers.

Ensure that the procedure is documented clearly, this should include;

- Whether the sample was an ABG/peripheral VBG or a capillary VBG.
- Was informed consent gained and if not why not?
- Was the Modified Allen’s test performed and what was the result?
- The time and date that the sample was taken and if necessary what time it was sent to the laboratory.
- The percentage of oxygen the patient is on and the temperature of the patient.
- Any complications during the procedure.
- Who the results should be reported to, or who will review the results, if the reviewer is not likely to be present when the results return.
Post Procedure

Ensure that there is adequate pressure on the insertion site to reduce haematoma, check that the patient is alright, observing for good circulation and sensation.

Inform the patient of when the results will be available and how that will be communicated to the patient, ensure that they have no queries.

If you were unsuccessful at taking a sample, you should have no more than 2 attempts, and discuss with your supervisor.

There are various alternatives to taking an ABG, but these will normally depend on the reason for taking a sample.

Alternatives include a capillary or peripheral VBG sample, which will be discussed. Additionally the below alternatives will only be done by an experienced or senior clinician.

1. An arterial line which is also called an art or an A-line. This is a thin catheter inserted into an artery, it is most commonly used in emergency or intensive care medicine and in anaesthesia, the line is used to obtain samples for arterial blood gas analysis.
2. Femoral or brachial artery, arterial gas sampling.
3. Obtaining a venous sample from a central venous catheter
4. Ultrasound guided arterial blood gas sampling, this is done by someone who is trained in both skills.
**Venous Blood Gas Sampling**

What is Venous Blood Gas (VBG) sampling and analysis?
Venous blood gas sampling is increasingly common, and is used frequently on respiratory wards.

A VBG is a blood test that looks at the amount of certain gases dissolved in venous blood, rather than arterial blood as with an ABG. The test predominantly examines the pH of the patient’s blood along with the amount of bicarbonate, as the respiratory elements (PaO$_2$ and PaCO$_2$) are much different and less reliable.

McKeever et al (2016) found that in patients with acute exacerbations of COPD (chronic obstructive pulmonary disease) pH and HCO$_3^-$ showed little variation when comparing results between arterial and venous samples.

This table gives the normal values for a VBG and demonstrates how different the respiratory values are compared to an ABG sample (see **ABG normal limits**).

<table>
<thead>
<tr>
<th>VBG Normal limits (Higgins 2011)</th>
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<tbody>
<tr>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>PaO$_2$</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>PaCO$_2$</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
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</table>

There are 2 main methods for obtaining a venous blood gas sample:

1. **Peripheral venepuncture** – using a gas syringe to obtain a venous sample of blood from a peripheral vein (the procedure for this is the same as described in the **Venepuncture study guide**).

2. **Capillary blood sampling (CBG)** – using a lancet to obtain a sample of capillary blood, usually from the ear lobe, and collected within a capillary blood gas tube.

Studies suggest that there is greater accuracy for the pH and the pCO$_2$ with CBG compared to peripheral VBG, however in practice you will see VBGs performed on adults more than CBGs. Conversely, CBGs are much more commonly seen in paediatric practice.
Some examples of gas syringes, capillary tubes and collection bottles below:

Figure 16, shows bottles that can be used for venous sampling, figure 17. Shows capillary blood gas tubes, these tubes contain the blood and are then put on the analyser in the tube.

Indications for taking a VBG or CBG
NICE guidelines (2018) recommend that regular arterial blood gases should be taken from a patient during an exacerbation of COPD, especially those receiving non-invasive ventilation (NIV) but as ABGs are known to be more painful and carry more risk for the patient, venous or capillary gas analysing is becoming increasingly common in clinical practice. In addition a venous blood gas can be taken in situations where monitoring of pCO₂ and H⁺ is desirable without multiple arterial sampling.

In clinical practice, patients with sepsis or suspected sepsis are increasingly having a VBG sample taken and analysed to help guide management. This is particularly the case if the gas machine is able to give a lactate reading as lactate forms an important part of the ‘Sepsis 6’ which form the early recognition and management of sepsis.

Contraindications and complications for peripheral VBG
The reasons for not performing, or taking caution when undertaking venepuncture to obtain a VBG are exactly the same as those for obtaining any venous sample as described in the Venepuncture study guide.

Also, be aware that there will be abnormal results if fluid is being infused distal to the puncture site.
Procedure – VBG & CBG

VBG sampling

Follow the normal procedure for venepuncture (as per the venepuncture study guide) but using a blood gas syringe for the venous sample. Standard syringes are not compatible with blood gas analysers.

- There are recommendations that the tourniquet be removed 1 minute before sampling to ensure results are not adversely affected.

CBG sampling

Capillary venous sampling uses different equipment, and will normally be taken from a patient’s ear lobe. For a demonstration of obtaining a CBG you can watch: Obtaining a CBG (RadiometerMedical)

Some may advocate the use of a rubefacient cream prior to sampling from an ear lobe for capillary VBG sampling.

[Note: Capillary blood sampling is commonly used in paediatrics, however this session does not cover you to take capillary blood samples from paediatric patients.]
Interpretation

Systematic approach to interpreting Arterial Blood Gases:

In order to interpret the results, it is simplest if you follow a systematic approach:

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<thead>
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<tbody>
<tr>
<td>1. Asses the patient</td>
<td>ABCDE</td>
<td></td>
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<tr>
<td>2. Check the PaO₂ in conjunction with SpO₂</td>
<td>Oxygenation of the patient</td>
<td></td>
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<tr>
<td>3. Assess the FiO₂ and A-a gradient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. What is the pH of the gas?</td>
<td>Respiratory &amp; Metabolic</td>
<td></td>
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<tr>
<td>5. What is the PaCO₂?</td>
<td></td>
<td></td>
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<tr>
<td>6. What are the HCO₃⁻ and the Base Excess</td>
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<tr>
<td>7. What is the ABG and is there any compensation?</td>
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You will need to decide if the ABG is abnormal and if the cause is respiratory or metabolic in origin, the CO₂ predominantly looks at the respiratory components in conjunction with the pH, O₂ and FiO₂ whereas the Bicarbonate and the base excess tend to address the metabolic aspect of an ABG.

1. **Assess the patient**

   As discuss, there are many indicators for taking a blood gas, and so the decision to obtain a blood gas will usually follow a full patient assessment, often using an ABCDE approach, taking into consideration:
   
   - The patient’s appearance, eg; cyanosis
   - The patient’s vital signs (NEWS2 score) including temperature
   - The patient’s history
   - Recent blood results including full blood count, coagulation, blood glucose and renal profile

2. **Partial Pressure of Oxygen (PaO₂)**

   This measures the amount of oxygen dissolved in the arterial blood.

   Ultimately in health the ideal PaO₂ is within the range of 12.0–14.6 kPa, (Driscoll 2008), and Higgins (2011) states above 10.5 kPa. These figures decrease with age, chronic lung disease, altitude, position of patient, (lower if patient supine), and the site that ABG was taken from. A VBG and CBG sample from an earlobe can be up to 1kPa lower than a radial ABG.
Also anaemia, pH, temperature and raised CO\textsubscript{2} levels can affect the PaO\textsubscript{2}, for more information please see references and look at the Oxygen Dissociation curve and the Bohr effect, (Driscoll et al, 2008).

Before performing an ABG, you should know what the patient’s inspired concentration of oxygen is. For example if a patient is on room air the atmosphere is made up of 21% Oxygen, the patient is therefore breathing 21% oxygen. You therefore need to know how much Oxygen each Oxygen mask delivers, please refer to the Oxygen study guide for a recap.

The PaO\textsubscript{2} should be compared with the oxygen saturation level. All of the factors above should be taken into consideration. If a patient has a low PaO\textsubscript{2}, supplementary oxygen may be required for an acutely unwell patient. If the patient is on supplementary oxygen and the PaO\textsubscript{2} is still low, further intervention is needed to deal with the hypoxia, and help should be sought.

3. Assess the FiO\textsubscript{2} and A-a gradient.

This is the volumetric fraction of oxygen in inhaled gas. If a patient was on room air at 21% oxygen, to record the FiO\textsubscript{2}- it is 0.21 (21/100).

You should be aware of the Alveolar-arterial gradient (A-a gradient) which is a measurement that calculates the difference between the oxygen concentration in the alveoli (what is being breathed in- PAO\textsubscript{2}) and the arteries (what has diffused through the alveoli and reached the circulation PaO\textsubscript{2}). In a young healthy individual the PAO\textsubscript{2} is always higher than the PaO\textsubscript{2}, with the PAO\textsubscript{2} normally being around 13kPa. This can be used to highlight causes of hypoxaemia such as pulmonary embolism (see McFarlane & Imperiale, 1994) and should be done for patients with an unexplained hypoxia or a hypoxia exceeding the degree of illness, as it can help diagnose the cause or evidence if the patient is ventilating effectively. In order to calculate the A-a gradient you will need the ABG results, the age of the patient and the FiO\textsubscript{2} (fraction of inspired Oxygen) there is a link to a calculator from Global RPh and Dr. F. Helmholz in references and additional reading. The A-a gradient is abnormal if it is elevated.

There is a simple way of estimating it:
In a normal healthy individual the PaO\textsubscript{2} is usually approximately 10kPa lower than the inspired oxygen, for example:

- If a patient is on 35% oxygen you can expect the PaO\textsubscript{2} to be around 25kPa.
- If a patient is on 24% oxygen you can expect the PaO\textsubscript{2} to be 14kPa

If the A-a gradient is increased (>10), this could be normal with advancing age and in patients
with chronic lung disease, or it could signify an acute underlying lung problem which is causing a problem with oxygen diffusion / gas exchange. For example, if you have a patient on 60% inspired oxygen and their PaO₂ was 15kPa you would be concerned that this was not normal and that they had an increased A-a gradient. (RCUK 2016)

Please be aware that patients at risk of hypercapnia (COPD patients, cystic fibrosis, neuromuscular disorders etc.) should have an ABG to diagnose hypercapnia, but be given oxygen to maintain saturations between 94 and 98%. If they are known to be at risk of hypercapnic respiratory failure, target saturations of 88-92% should be maintained. This should also be documented on the patient’s NEWS2 chart (O’Driscoll et al 2017), meaning that the SpO₂ scale 2 should be used, please see NEWS2 study guide year 2.

4. Assess the pH

Many reactions within the cells are controlled by enzymes that can only function between rigid parameters.

The pH is inversely proportional to the number of hydrogen ions (H⁺) in the blood. The more H⁺ present in the blood the lower the pH and the more acidic the blood will be.

The body produces 14 500,000,000 nmol H⁺ daily (Resuscitation Council UK 2016). If unrestricted these ions would cause a massive acidaemia, the body prevents this through a series of buffers that mop up H⁺, proteins, haemoglobin, plasma proteins and bicarbonate (within plasma).

Buffering is a transient process as the buffering agents will ultimately be consumed and acids will regenerate. The lungs and kidneys are therefore required to eliminate acids and restore buffers. The liver has also been recognised as an important organ in maintaining acid/base homeostasis (Scheiner et al 2017).

<table>
<thead>
<tr>
<th>Normal limits (Resuscitation Council UK 2016); these are subject to variation from Trust to Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acidaemia</th>
<th>Alkalaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.35</td>
<td>7.45</td>
</tr>
</tbody>
</table>
5. Partial pressure of Carbon Dioxide (PaCO₂):

PaCO₂ is the partial pressure of carbon dioxide in arterial blood.

When CO₂ is dissolved in the blood it is converted to carbonic acid and releases an H⁺. Therefore, the more CO₂ the more H⁺. The Resuscitation Council UK (2016) state that a normal PaCO₂ is 5.3kPa with the range being between 4.7 and 6 kPa.

<table>
<thead>
<tr>
<th>Normal limits (Resuscitation Council UK 2016): these are subject to variation from Trust to Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
</tr>
<tr>
<td>[or may be seen as 35 to 45mmHg]</td>
</tr>
<tr>
<td>Acidaemia</td>
</tr>
<tr>
<td>4.7</td>
</tr>
</tbody>
</table>

6. Bicarbonate (HCO₃⁻)

This is often referred to as the metabolic component, rising levels of HCO₃⁻ make the blood more alkaline and a reduction of HCO₃⁻ makes the blood more acidic. It is known as a buffer: if the pH rises the kidneys respond by excreting HCO₃⁻ in the urine. Likewise if the pH becomes acidotic the kidneys retain HCO₃⁻.

<table>
<thead>
<tr>
<th>Normal limits (Resuscitation Council UK 2016): these are subject to variation from Trust to Trust</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
</tr>
<tr>
<td>Acidaemia</td>
</tr>
<tr>
<td>22</td>
</tr>
</tbody>
</table>

Base Excess (BE)

This is the amount of strong base which would need to be added or subtracted from a substance in order to return the pH to normal. It indicates how much the body is buffering to maintain a neutral pH, therefore, infers the amount of alkali base that needs to be added to or
taken away from blood to restore a neutral pH.

7. Collating the findings of ABG's and characterising the problem.

There is a need to calculate if the abnormality is respiratory or metabolic in origin:

- Respiratory Acidaemia
- Respiratory Alkalaemia
- Metabolic Acidaemia
- Metabolic Alkalaemia

Then it should be determined whether the body has tried to compensate for the abnormality and how well it has compensated. Together, this can help provide a differential diagnosis and enable formulation of a management plan. A potentially useful tip is to draw arrows next to the result - is the result high or low?

If the pH and the CO₂ are abnormal, but going in different directions, then the origin of the abnormality will tend to be respiratory.
Compensation

The body’s defence system will automatically try to correct an abnormal pH, this is compensation.

For example, if a patient has a metabolic acidosis, (such as diabetic ketoacidosis /DKA) the body will compensate to try to decrease the acidosis, therefore the patient will have an increased respiratory rate as they try to breathe out more CO₂. Respiratory compensation is quick but hard to maintain as the patient will tire rapidly.

Whereas if a patient has an acute exacerbation of a chronic respiratory condition, with a respiratory acidosis, the body would try to compensate but metabolic compensation through the kidneys takes longer, up to 3 days.

Fully compensated arterial blood gas results are when the acidaemia/ alkalaemia has been corrected so that the pH is in normal limits.

Partial compensation is when compensatory mechanisms have occurred but the pH remains abnormal.
Venous Blood Gas (VBG) Interpretation:
When analysing a VBG use the same systematic approach as when interpreting an ABG the following considerations are needed:

- There is no way to correlate PaO\textsubscript{2} between venous blood gases and arterial blood gases.
- Peripheral VBG pH tends to only be 0.02-0.04 lower than ABG pH.
- Peripheral VBG HCO\textsubscript{3}\textsuperscript{-} tends to be 1 to 2 mmol/L higher than in ABG.

When interpreting VBG’s consider why you are taking VBG’s, how you are taking them (capillary may be more accurate than peripheral) and the principles that apply to interpreting ABG’s. Normal are listed below, although this is venous blood and oxygenation should be taken from saturations or an ABG.

<table>
<thead>
<tr>
<th>VBG Normal limits (Higgins 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
</tr>
<tr>
<td>PaO\textsubscript{2}</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>PaCO\textsubscript{2}</td>
</tr>
<tr>
<td>HCO\textsubscript{3}^-</td>
</tr>
</tbody>
</table>
Anion Gap
The anion gap (AG) can be calculated and used to differentiate different disease pathways causing imbalances of the pH. An abnormal AG is important clinically but an abnormal AG in relation to metabolic acidosis is especially significant.

Plasma is filled with salts and acids or electronically charged cations and anions, plasma should be electrochemically neutral. The primary cation is sodium (Na$^+$), the primary measured anions tend to be chloride Cl$^-$ and bicarbonate HCO$_3^-$ in serum. Sodium concentration should be more than the combined concentration of Cl$^-$ & HCO$_3^-$ . One of the commonest ways to define the AG is the difference between the sodium concentration in plasma and the chloride and bicarbonate concentrations. Some people will include the Potassium concentration in the equation, follow Trust guidelines. Using urea and electrolyte or blood results the AG is calculated:

AG (in mmol/L) = [Na$^+$] - ([Cl$^-$] + [HCO$_3^-$])

Where [Na$^+$] is the sodium concentration in mmol/L in the plasma

[Cl$^-$] is the plasma chloride concentration (mmol/L)

And [HCO$_3^-$] is the plasma bicarbonate concentration in mmol/L.

Different analysers are available, and therefore normal reference interval should be checked with the Trust you are in, traditionally the reference interval is between 8 and 16 mmol/L but can be much lower.

Some causes of a lower anion gap are hypoalbuminaemia or lithium intoxication.

Patients can have a normal anion gap but with a metabolic acidosis, this is called hyperchloremic metabolic acidosis. Potential causes of this are diarrhoea, adrenal insufficiency, pancreatic intestinal and biliary fistulas or renal tubule acidosis.

Some causes of a raised anion gap associated with metabolic acidosis are renal failure, diabetic ketoacidosis, starvation, alcoholic ketoacidosis, lactic acidosis, a hyperalbuminaemia and potentially IgA myeloma.

The AG can help aid investigations into the cause of a metabolic acidosis.
Worked example for ABG interpretation:

Example 1

A 74 year old male has been sent to AMU from home with difficulty in breathing. He started with cold-like symptoms a week ago, his breathing has been getting worse since then and he now has a cough productive of yellow sputum.

He is normally fit and well. He has been struggling to sleep and has become increasingly breathless over the past 3 days and his GP sent him in.

He has been started on 40% oxygen via venturi on arrival. His SpO₂ reading is 92%.

<table>
<thead>
<tr>
<th></th>
<th>Results</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂</td>
<td>9.5</td>
<td>↓</td>
</tr>
<tr>
<td>FiO₂</td>
<td>0.40 (40%)</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.29</td>
<td>↓</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>8.2</td>
<td>↑</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>23</td>
<td>~</td>
</tr>
<tr>
<td>BE</td>
<td>0</td>
<td>~</td>
</tr>
</tbody>
</table>

1. Assess the patient
2. Check the PaO₂ in conjunction with SpO₂
3. Assess the FiO₂ (and the A-a gradient)
4. What is the pH of the gas?
5. What is the PaCO₂?
6. What are the HCO₃⁻ and the Base Excess
7. What is the ABG and is there any compensation?

1. Assess the patient:
   - More information would be needed about this patient, including a full ABCDE assessment and a review of his history, NEWS2 chart, blood results and the results of any other investigations that have been performed.

2. Check the PaO₂ in conjunction with the SpO₂:
   - Is the PaO₂ with in the normal range? No, it’s low. [He is hypoxaemic]
   - Is the SpO₂ measurement normal? No, it is also low. [He is hypoxic]
3. **Assess the FiO$_2$ (and the A-a gradient):**
   - He is on 40% O$_2$ via a venturi facemask, (he may need oxygen increasing).
   - His A-a gradient is elevated

4. **What is the pH of the gas?**
   - 7.29 which is <7.35, so the pH is low. [He is acidaemic]

5. **What is the PaCO$_2$?**
   - 8.2 which is >6.0, so it’s high. [He is hypercapnic]

6. **What are the HCO$_3^-$ and Base Excess?**
   - They are both within the normal ranges.

7. **What is the ABG and is there any compensation?**
   - This ABG shows hypoxia and a respiratory acidosis.
   - There is no metabolic compensation.

The most likely cause would be a pneumonia or a first presentation of COPD (infective exacerbation), which could be confirmed through a chest x-ray, bloods and a sputum sample.

**Example 2**

A 34 year old female has attended AED from home with consistent vomiting. She started with abdominal ache and vomiting symptoms 48 hours ago, her vomiting has been getting gradually worse and she is not keeping fluids down and feels weak.

She is normally fit and well. She ate some home cooked chicken that tasted “funny” a few hours before she started vomiting, she rang the helpline and was told to go to the AED.

<table>
<thead>
<tr>
<th></th>
<th>Results</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PaO$_2$</strong></td>
<td>10.8</td>
<td>~</td>
</tr>
<tr>
<td><strong>FiO$_2$</strong></td>
<td>0.21 (21%)</td>
<td>↑</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>7.53</td>
<td>↑</td>
</tr>
<tr>
<td><strong>PaCO$_2$</strong></td>
<td>6.8</td>
<td>↑</td>
</tr>
<tr>
<td><strong>HCO$_3^-$</strong></td>
<td>31</td>
<td>↑</td>
</tr>
<tr>
<td><strong>BE</strong></td>
<td>+10</td>
<td>↑</td>
</tr>
</tbody>
</table>
8. Assess the patient:
   a. More information would be needed about this patient, including a full ABCDE assessment and a review of her history, NEWS2 chart, blood results and the results of any other investigations that have been performed.

9. Check the PaO₂ in conjunction with the SpO₂:
   a. Is the PaO₂ with in the normal range? Yes, it is normal
   b. Is the SpO₂ measurement normal? Yes it is normal

10. Assess the FiO₂ (and the A-a gradient):
    a. She is on room air at 21%
    b. Her A-a gradient is normal

11. What is the pH of the gas?
    a. 7.53 which is >7.35, so the pH is high. [She is alkalotic]

12. What is the PaCO₂?
    a. 6.8 which is >6.0, so it’s high. [She is hypercapnic]

13. What are the HCO₃⁻ and Base Excess?
    a. HCO₃⁻, This is 31, so this is high.
    b. BE, This is +10, so this is high [This suggests a metabolic component]

14. What is the ABG and is there any compensation?
    a. This ABG shows a metabolic alkalosis.
    b. As the pH, the HCO₃⁻, BE and the C0₂ are moving in the same direction, this suggests that this is a partially compensated metabolic alkalosis.
    c. It is partially compensated as the pH is not within the normal range.

The most likely cause is dehydration from recurrent vomiting (loss of acidic stomach contents), secondary to food poisoning.
Appendix 1:
Clinical Skills sharps management for the School of Medicine, Liverpool
If you sustain a sharps injury in clinical practice, please also adhere to Trust policy, if you sustain an injury in CSTLC, such as in The Learning Zone please also adhere to the CSTLC policy.

Remove
• Remove sharp
• Sharps with unknown contaminants may need to be retained for analysis

Squeeze it
• Squeeze the site to make it bleed

Wash it
• Wash the site thoroughly with soap under running water
• Do not scrub

Dry it
• Dry the site thoroughly

Dress it
• Apply a dressing to the site

Report it
• Report the injury to your supervisor and manager of the clinical area
• Dr Beddoes(ebeddoes@liv.ac.uk) must be emailed with all injuries sustained in clinical practice.

Document it
• Complete an incident form
• Attend Occupational Health or Accident and Emergency Department
References and further reading


BNF published by NICE: [The BNF: Oxygen](Accessed 30/06/2020).


Helmholz, F. A-a O₂ Gradient Calculator: MD Calc: A-a O₂ Gradient [Accessed 30/06/2020]


Kaufman, David A. Interpretation of Arterial Blood Gases (ABGs) : Clinical education interpretation of ABG's [Accessed 30/06/2020]


NICE guideline (2018) Chronic obstructive pulmonary disease in over 16s: diagnosis and management [NG115] Published date: December 2018 Last updated: July 2019 Chronic
obstructive pulmonary disease in over 16s: diagnosis and management  
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WHO (2009); WHO guidelines on hand hygiene in Health Care; Hand hygiene tools and resources [Accessed 30/06/2020]

Accessed 30/06/20:

  Henderson–Hasselbalch equation
  Anion Gap;
- Dr Chris Nickson, last update April 23, 2019 [Life in the fast lane: Anion gap](https://www.lifeprogress.com/health/anion-gap)
Picture Credits

1. **Figure 1**: Vascular anatomy of the lower arm – By Henry Vandyke Carter - Henry Gray (1918) Anatomy of the Human Body (See "Book" section below)Bartleby.com: Gray’s Anatomy, Plate 528, Public Domain, [Wikipedia Commons, lower arm anatomy](https://commons.wikimedia.org/wiki/Plate_528)

2. **Figure 2**: Clinical Skills Teaching and Learning Centre, University of Liverpool

3. **Figure 3**: Clinical Skills Teaching and Learning Centre, University of Liverpool


5. **Figure 5**: Clinical Skills Teaching and Learning Centre, University of Liverpool

6. **Figure 6**: Clinical Skills Teaching and Learning Centre, University of Liverpool

7. **Figure 7**: Clinical Skills Teaching and Learning Centre, University of Liverpool

8. **Figure 8**: Clinical Skills Teaching and Learning Centre, University of Liverpool

9. **Figure 9**: Clinical Skills Teaching and Learning Centre, University of Liverpool

10. **Figure 10**: Clinical Skills Teaching and Learning Centre, University of Liverpool

11. **Figure 11**: Clinical Skills Teaching and Learning Centre, University of Liverpool

12. **Figure 12**: Clinical Skills Teaching and Learning Centre, University of Liverpool

13. **Figure 13**: Clinical Skills Teaching and Learning Centre, University of Liverpool

14. **Figure 14**: Clinical Skills Teaching and Learning Centre, University of Liverpool

15. **Figure 15**: Capped ABG syringe: [Capped ABG syringe: Medistudents](https://www.medistudents.com)

16. **Figure 16**: Monovette Blood gas collection: Permission kindly granted by Sarstedt

17. **Figure 17**: Capillary glass tubes and stirrers, Permission to use image kindly granted by MARIENFELD. Paul Marienfeld GmbH & Co. KG, Germany.

18. **Figure 18**: Monovette Capillary Blood gas collection: Permission kindly granted by Sarstedt