Blood gas analysis is used in the holistic care of patients who are critically ill or deteriorating and must be available in all critical care units (Faculty of Intensive Care Medicine and Intensive Care Society, 2019). Samples can be arterial, venous or mixed venous; arterial blood gases (ABGs) are taken from arteries and give a real-time indication of the patient’s oxygenation, ventilation, acid-base balance and metabolic status. An ABG can be taken by sampling blood from an arterial line or performing an arterial puncture (if staff are trained and competent to do so). This article focuses on ABGs. A glossary of key terms is given in Box 1.

As with any numerical analysis, a blood gas test should be used together with a holistic assessment of the patient using the systematic airway, breathing, circulation, disability, exposure approach (Resuscitation Council UK (RCUK), 2021). A systematic approach to analysing blood gases should also be used. Basic analysis of ABGs is part of step one of the adult critical care competency framework by the Critical Care Networks – National Nurse Leads (CC3N) (2015).

Indications
ABGs are used to assess patients in critical care, where many have a degree of respiratory support – for example, invasive ventilation, nasal high-flow oxygen, non-invasive ventilation or humidified oxygen (RCUK, 2021). Only staff trained and competent to perform arterial punctures or access arterial lines should undertake this skill; they should be trained, for example, by undertaking the CC3N’s step one competencies or a local competency assessment. Nurses should, at all times, follow local policies and procedures, as well as the Nursing and Midwifery Council’s (2018) Code.

ABGs can provide reassurance that a patient is ventilating their lungs adequately.
Hospital policies and procedures: Is the PaO2 >13kPa? If so, it might mean the amount of support and oxygen being delivered to the patient needs to be decreased.

- Does the patient have acidosis (pH <7.35) or alkalosis (pH >7.45)? Take into account whether the blood gas is taken while the patient is receiving supplemental oxygen.
- Is the PaO2 <10kPa? If the patient is hypoxaemic, oxygen should be administered or the FiO2 increased, and the patient escalated in line with or their respiratory function is adequate, in conjunction with pulse oximetry (O’Driscoll et al, 2017). ABGs also assess the metabolic needs of a patient who is critically ill, allowing for timely escalation if needed. A change or deterioration in a patient’s condition should trigger a blood gas sample to be taken; this could be when titrating mechanical ventilation settings, such as tidal volumes, respiration rate or FiO2 (Lian, 2010).

**Principles of blood–gas analysis**

**What is measured**

ABGs have five key pieces of information:
- PaO2 in arterial blood;
- pH;
- PaCO2 in arterial blood;
- HCO3;
- Base excess;

A common blood gas result is shown in Box 2; reference values are given in Table 1.

**Systematic assessment of blood gases**

A systematic, five-stage approach should be used when analysing blood gases (RCUK, 2021). It can be used in conjunction with a flowchart (Fig 1) to work through an ABG systematically. Answers to the following questions should be ascertained:
- How is the patient? Does senior help need to be requested?
- Does the patient have hypoxaemia?
- Take into account whether the blood gas is taken while the patient is receiving supplemental oxygen;
- Is the PaO2 <10kPa? If the patient is hypoxaemic, oxygen should be administered or the FiO2 increased, and the patient escalated in line with hospital policies and procedures;
- Is the PaO2 >13kPa? If so, it might mean the amount of support and oxygen being delivered to the patient needs to be decreased;
- Does the patient have acidosis (pH <7.35) or alkalosis (pH >7.45)?

**Table 1. ABG values and clinical significance in critical care**

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<thead>
<tr>
<th>Measure</th>
<th>Normal values</th>
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**Box 2. A common ABG result**

- PaO2 – 12.5kPa
- PaCO2 – 4.8kPa
- pH – 7.4
- HCO3 – 23mmol/L
- Base excess – +1
- SaO2 – 97%
- Hb – 9.4g/dL
- K+ – 4.0mmol/L
- Na+ – 136mmol/L
- Lactate – 1.2mmol/L

ABG = arterial blood gas.

**Box 1. Glossary**

- FiO2 – fraction of inspired oxygen
- Hb – haemoglobin
- HCO3 – bicarbonate
- K+ – potassium ion
- kPa – kilopascal
- Na+ – sodium ion
- PaCO2 – partial pressure of carbon dioxide
- PaO2 – partial pressure of oxygen
- SaO2 – oxygen saturation; percentage of oxygen bound to haemoglobin
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**Fig 1. Arterial blood gas analysis flowchart**

- Normal PaO2 → Low Rapidly correct <8kPa = hypoxia
- pH >7.45
- pH <7.35
- Alkalosis
- PaCO2 <4.5kPa HIGH
- HCO3 >26mmol/L LOW
- Acidosis
- PaCO2 >6.6kPa HIGH
- HCO3 <22mmol/L LOW

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Compensated and uncompensated blood gas

The body is well versed in trying to maintain homeostasis. As mentioned, a small change in CO2 or HCO3− can alter the pH in the body; the body will try to revert the pH to normal levels despite physiological derangements. Remember: pH is determined by the concentration of hydrogen ions (H+).

Excess CO2 will dissolve in water (in the blood) to form carbonic acid, releasing more H+ and, therefore, decreasing the pH (CO2 + H2O → H2CO3 → H+ + HCO3−). Conversely, HCO3− can react with excess H+ to create water, neutralising excess acid. A decrease in pH (more acidic) will lead to an increase in respiratory rate (to excrete more CO2) called respiratory compensation. A decrease in pH will also lead to more HCO3− being released by the kidneys – this is metabolic compensation. The release of HCO3− (metabolic compensation) takes much longer than respiratory compensation.

When deciding whether a gas is compensated or uncompensated, it is important to look at which component is likely to have the most influence. In Table 2, Example 1 shows a patient with an FiO2 of 21%. The patient’s pH is normal but the PaCO2 is high (which should make the pH lower). The HCO3− is high, so the HCO3− has the most influence; as such, this is a fully compensated metabolic alkalosis. It is fully compensated because the pH is normal, alkalotic as the pH is on the alkalosis side (pH > 7.35), and metabolic as the HCO3− is raised, keeping with increasing the pH. This can be seen in patients with severe vomiting.

Example 2 (Table 2) is for a patient with an FiO2 of 30%, who we can say is acidic (the pH is < 7.4). Respiratory acidosis is likely as the PaCO2 is >6kPa; the HCO3− is increased (>26mmol/L), so this is classed as partially compensated respiratory acidosis (partially, as the pH remains deranged). Patients presenting to hospital with exacerbations of chronic obstructive pulmonary disease can show this, as their body has learned to compensate for poor respiratory function over several years (Box 3).

Red flags and interventions

If the PaO2 is <8kPa, the patient is hypoxaemic and needs oxygen. This can be delivered via a non-rebreather mask or by use of an arterial line can decrease repeated stabbing (see part three of this series for more information).

Conclusion

ABG analysis can form part of a holistic review of an adult who is critically ill. Only trained, competent staff should take an ABG, and results should always be interpreted by a competent practitioner. NT

References


Critical Care Networks – National Nurse Leads (2015) National Competency Framework for Registered Nurses in Adult Critical Care: Step 1 Competencies. CC3N.


Table 2. Example ABG results

<table>
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<td>6.7kPa</td>
</tr>
<tr>
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<td>7.3</td>
<td></td>
<td>12.5kPa</td>
</tr>
</tbody>
</table>

ABG = arterial blood gas; in reference range; ↑ above reference range; ↓ below reference range.

● What is the PaCO2 and is there an abnormality with ventilation?
  ● If the pH is < 7.35 and the PaCO2 is high, it indicates a respiratory acidosi;
  ● If the pH is > 7.45 and the PaCO2 is low, it indicates a respiratory alkalosis;
  ● What is the HCO3−?
    ● If the pH is < 7.35 and the HCO3− is < 22mmol/L, there is a metabolic acidosis;
    ● If the pH is > 7.45 and the HCO3− is > 26mmol/L, there is a metabolic alkalosis.

Following this, all other aspects of the blood gas should be reviewed, prioritising and treating what is found.

Box 3. Fully compensated respiratory acidosis

Arterial sample, on room air (no supplemental oxygen)
  ● pH = 7.35
  ● PaO2 = 12.2kPa
  ● PaCO2 = 9.6kPa
  ● HCO3− = 26mmol/L

Oxygenation is adequate, the pH is normal (but on the acidic side <7.4); PaCO2 is >6kPa and, therefore, is a respiratory issue and HCO3− is high.

This should be discussed and escalated with the senior nurse and medical team. Other contributing factors should be considered, such as opiate overdose or a decrease in Glasgow Coma Scale score.

Patient experience

Arterial puncture is often used to obtain an ABG [Crawford, 2004]. This can be a painful, unpleasant experience; almost half of participants in Crawford’s (2004) audit reported pain scores of >5 out of 10. Local anaesthetic was rarely offered (n=26/66), but it can help to reduce pain. Matheson et al’s (2014) study showed that infiltration of lidocaine reduced pain scores, but the study was small in scale (n=9) and only partially randomised.

Topical anaesthetics can be used, but require time to work and, therefore, can delay the sample being taken [Aaron et al, 2005]. BTS guidance recommends the use of local anaesthesia for all ABG sampling [O’Driscoll et al, 2017].

Use of an arterial line can decrease repeated stabbing (see part three of this series for more information).

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