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POSITION PAPER

Australian and New Zealand Society of Respiratory Science position statement for arterial blood gas sampling

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Abstract

The assessment of gas exchange under varying ambient and metabolic conditions is an important and fundamental investigation of respiratory function. The gold standard is an arterial blood gas (ABG) sample; however, the procedure is not universally performed by medical scientists, is not standardised, and is typically taught by a subjective Halsted 'see one, do one' approach. The Australian and New Zealand Society of Respiratory Science recognised the need to create an ABG position statement that includes the required pre-requisite education, an evidence-based procedure and the minimum reporting and competency assessment requirements. This position statement aims to minimise patient discomfort, to improve puncture success rate and reduce the potential for sample handling and analysis error. Importantly, this position statement translates to all relevant health professionals, including medical officers, scientists, nursing staff and allied health.

Introduction

Arterial blood gas (ABG) analysis is the gold standard for assessing acid–base balance, adequacy of ventilation and oxygen saturation in both acute and chronic care. The assessment of gas exchange under varying ambient and metabolic conditions is a fundamental respiratory function investigation; however, the procedure of ABG sampling is currently not standard practice for all respiratory and medical scientists within Australia and New Zealand. Importantly, there is a lack of standardised procedure, including formalised education, training and assessment of competency, which increases the potential for poor sampling technique and inaccuracies.

In consideration of this, the Australian and New Zealand Society of Respiratory Science (ANZSRS) board of directors formed a working group to build an evidence-based framework for ABG sampling. The presented position statement has been reviewed and fully endorsed by the ANZSRS Board of Directors.

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Clinical respiratory and medical scientists are employed under a variety of classifications across Australia and New Zealand. All have the common minimum requirement of an appropriate bachelor's degree with pathophysiology, anatomy and/or physiology curricula.[2,3] These are required for clinical diagnostic scientific measurement, which includes ABG sampling. ABG sampling is an invasive and potentially painful procedure; however, training opportunities are limited. Medical and scientific trainees are almost exclusively taught using Halsted's 'see one, do one, teach one'. Prosthetic mannequin arms, simulations, and virtual and augmented reality can effectively enhance learning outcomes[4,5]; however, these technologies are emerging, and current availability is limited.

Direct and derived ABG components assist in the identification of clinical paradigms that guide acute and chronic treatment. The need for ventilatory support, supplemental oxygen and the effectiveness of therapeutic interventions can be reviewed and titrated very rapidly utilising ABG results. In respiratory medicine, an accurate measurement of pressure of arterial carbon dioxide ($PaCO_2$) and/or oxygen (PaO_2) is required for the calculation of shunt, physiological dead space, alveolar-arterial oxygen tension gradient, and the need for ambulatory or in-flight oxygen

support. Non-invasive alternatives are often poor surrogates. Pulse oximetry is calibrated empirically within the survivable range and thus becomes increasingly inaccurate at values below 85%[6] (Grade 1B). Capillary and venous blood PO_2 are poorly associated with PaO_2 (Grade 1A),[7–9] and venous PCO_2 has no association with $PaCO_2$ values above 45 mmHg (Grade 1A).[8,9] End-tidal carbon dioxide pressure becomes increasingly discordant with $PaCO_2$ in the presence of ventilation/perfusion mismatch (Grade 1B).[10]

Methods

The authors were selected by the ANZSRS board of directors through an Expression of Interest process to meet geographical and sex diversity principles. This position paper was developed using a modified Delphi method. In summary, the authors searched for relevant literature from primary electronic databases to January 2024 (e.g. MEDLINE, Cochrane Library and Web of Science). When no evidence existed, Google Scholar searches were used to access non-published, institutional standard operation procedures and manuals. The reference lists of the identified articles were manually searched to further identify relevant publications. Selected references by each author were collated and then assessed for accuracy by one senior author, and any discordance was resolved through discussion. When relevant, the strength of recommendation (strong (1) or weak (2)) and grading of evidence (A (high-quality meta-analysis), B (Phase 3 trials), C (Phase 2 trials) or D (expert panel consensus)) as reviewed by this expert group are provided[1] (Table 1).

Table 1 Summary of primary recommendations

1. Arterial blood sampling is within the medical scientist's scope of practice following required education, training and ongoing competency assessment
2. Sampling from the radial artery using a small-bore needle (25 gauge) results in fewer complications, however with similar reported pain scores (Grade 2C)
3. The use of local anaesthetic does not improve patient outcomes (Grade 2C)
4. In normal ambient conditions, samples are to be analysed within 15 min of extraction, or within 5 min in high oxygen shunt studies (Grade 1C)
5. Samples are considered inaccurate when (Grade 2C):
   - air bubbles are present that cannot be evacuated within 30 s
   - there are analysis delays outside the recommended in point 4
   - they are exposed to pressure changes
   - there is inadequate mixing of anticoagulant
   - no correction is made for extreme core temperature.

Sample collection

Sampling should occur in a private, well-lit area with adequate space for non-ambulatory patients and required equipment. The operator must identify the patient, test indication, required testing environment and any contraindications or considerations that might affect the sampling site or method utilised. Verbal, informed consent must be obtained following a clear and concise explanation of the procedure, the importance for obtaining the sample(s), the potential risks and potential adverse effects. Contraindications for ABG sampling include known deficiency of collateral circulation to the distal upper extremity (for radial sampling) and sampling from sites with overlying skin infection. Use of anticoagulants or presence of coagulopathies is a relative contraindication due to an increased risk of bleeding and haematoma formation.[11]

While the radial artery has a smaller diameter than the brachial, it is the preferred site as it is more superficial and has good collateral circulation, with less surrounding structures that might be inadvertently damaged.[12] For radial samples, a modified Allen's test is commonly recommended to assess adequate collateral flow[12]; however, there are some conflicting data about its utility.[13] A site that produces a negative Allen's test is considered a contraindication as there is risk of significant hand ischaemia. Sampling from the brachial artery may be considered as an alternate site in certain situations in those with relevant training.

Arterial punctures are known potentially to create more discomfort than venous ones due to their thicker muscular (tunica media) and innervated (tunica adventita) layers. Patients' negative previous experiences with ABGs correlate with their current pain scores and their anticipatory anxiety of repeat punctures.[14] Current evidence suggests that neither needle gauge selection nor use of local anaesthetic is effective in reducing the perception of pain during sampling. Two randomised controlled trials found puncture success rate and patient pain scores to be similar when sampling with either a 23- or 25-gauge needle.[14,15] However, a higher rate of complications was seen with the larger 23 gauge, including haematoma, tenderness and/or paraesthesia.[15] Two separate randomised controlled trials of topical amethocaine and lidocaine found no effect on reported pain scores, despite a patient preference to include these in standard procedure.[16,17] Cryoanalgesia using ice was shown to lead to lower pain scores in a randomised trial; however, this was in a small single-centre study using the same experienced operator.[18]

The favoured forearm (non-dominant or more easily palpated) is positioned on a stable surface facing the

operator so that the needle, and so the operator's line of sight, is aligned with the artery, against blood flow. The forearm should be relaxed and the wrist hyperextended, supinated with support to enhance superficial access (Fig. 1). Adequate time and care are taken to locate and envisage optimal location. In circumstances where the radial artery is difficult to palpate, a portable Doppler ultrasound device can assist in identifying its location,[11,19] which requires additional, relevant training.

Adherence to local infection control policies, including hand hygiene, personal protective equipment, sharps disposal systems and needle safety, is essential. After donning of gloves, the chosen site is swabbed with alcohol and allowed to air dry. A standard ABG kit is assembled, which includes a syringe containing dry lithium heparin or sodium heparin, the preferred 25-gauge needle, rubber stopper or block and a syringe cap.[11]

The syringe plunger should be initially set at the required volume and then, with needle in situ, is held like a pen or dart in the operator's dominant hand. Artery location and depth are palpated with index and middle fingers of the operator's non-dominant hand, located between the distal radius and the tendon of the flexor carpi radialis. The needle is positioned, bevel facing upward, at a 30–45° angle, directed at a point just below the operator's index finger of the non-dominant hand (Fig. 1). The needle is slowly inserted percutaneously until the first sight of blood, which should easily and passively fill to the required syringe volume, without physically retracting the syringe plunger.[11]

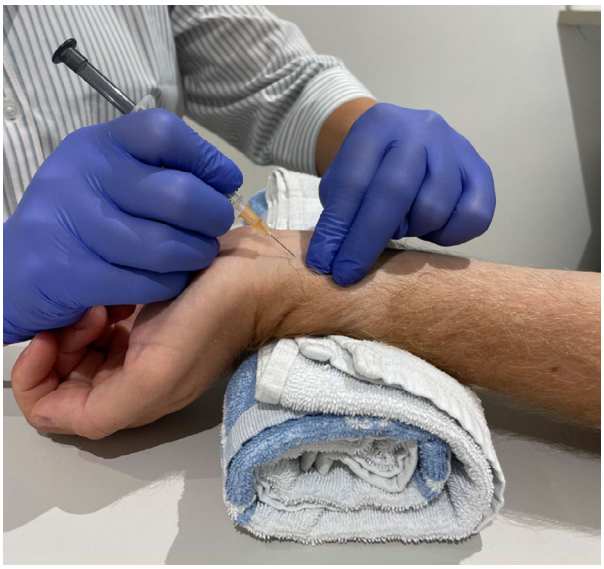

Figure 1 Image of radial arterial blood sampling procedure. The patient's wrist is supinated and hyperextended utilising support. The operator is facing across from the patient, with needle of syringe and line of sight aligned with the artery, against blood flow. The syringe is held like a dart at a 30–45° angle with needle bevel facing upward.

If blood does not begin to fill the syringe, the needle can be slowly withdrawn to just below the skin surface, angled slightly towards the palpated artery and then re-advanced. It is not recommended to repeat this action more than three times or if the patient does not give consent. If no arterial sample is obtained, the needle must be completely withdrawn, pressure applied to the site, and the needle discarded. While there is no supporting evidence, it is recommended to change operators after three failed attempts, with patient consent (Grade 2D).

Once the required blood volume has been collected, the needle is slowly withdrawn from the patient with immediate pressure applied at the puncture site for approximately 5 min.[11] The puncture site is observed for local haemorrhage or development of a haematoma and dressed appropriately.

Sample handling

Several sample handling conditions can significantly alter the results and lead to incorrect interpretation, as summarised in Table 2. Any air bubbles should be carefully evacuated within 30 s,[20] and syringes should be capped and rolled vertically for at least 10 s to distribute evenly the anticlotting agent. Modern, universally used plastic syringes allow for gas diffusion. Therefore, time delay to analysis has the potential to alter both $PaCO_2$ and PaO_2 due to both gas diffusion through the syringe and continued erythrocyte metabolism. To calculate shunt (the proportion of cardiac output that does not participate in gas exchange), sampling occurs following 15–20 min of breathing a fraction of inspired oxygen of 1.0 ($100\%O_2$). At high oxygen concentrations, measured PaO_2 falls at a faster rate, by 9–13 mmHg per min in the first 5–10 min,[21,22] which overestimates shunt calculation by 0.6% per min.[22] Therefore, shunt study samples need to be analysed within 5 min of collection; otherwise, there is significant risk of false positives. Samples have historically been seen to be stable for up to 45 min when stored in an ice slurry[23]; however, a recent study found ice water to worsen the stability of PaO_2 due to oxygen diffusion from the slurry to the sample and a left-shift of the oxyhaemoglobin dissociation curve increasing the affinity for oxygen, thereby erroneously increasing PaO_2.[24]

A point-of-care blood gas analyser minimises time to analysis as a multitude of factors may delay general diagnostic unit analysis in a clinical setting. Portable analysers, with single-use cartridge systems, significantly reduce maintenance and calibration requirements. However, these will typically measure fewer analytes and have narrower calibration ranges. The analysis of elevated PaO_2 above 150 mmHg, such as with shunt studies, should be done

Table 2 Potential sources of inaccuracy associated with arterial blood gas sample handling

Source of inaccuracy	Primary inaccuracy	Cause of inaccuracy
Delay from sampling to analysis	Reduced PaO_2, pH Increased $PaCO_2$	Continued erythrocyte metabolism[25]
	Altered PaO_2, $PaCO_2$ by atmospheric condition	Gas diffusion from sample to atmosphere
Ambient temperature exposure	Reduced PaO_2	Unstable after:
	Increased $PaCO_2$, reduced pH	15 min in normal conditions[23] 5 min following shunt study (high FIO_2)[21,22,24]
		Unstable after:
		30 min in normal conditions[23,24,30,31]
Air bubbles	Increased PaO_2, pH Reduced $PaCO_2$	Sample diluted with ambient air[32]
Inadequate mixing of sample with anticoagulant	Altered pH, $PaCO_2$, PaO_2	Excess: low pH of anticoagulant[25] Absence: clotting
Pressure changes (pneumatic tube)	PaO_2	Disrupts solubilised oxygen, unless in pressure-sealed cannister[33,34]
Not correcting for core body temperature outside 35–39°C	Under and overestimation of PaO_2, $PaCO_2$ in hyper- and hypobaria respectively	Temperature effects on gas solubility[25,26]

FIO_2, inspired oxygen fraction; $PaCO_2$, pressure of arterial carbon dioxide; PaO_2, pressure of arterial oxygen.

using a device that has been calibrated within an appropriate range (i.e. up to 500 mmHg). The analyser typically adjusts the sample to 37°C through a solid-state thermostat. However due to temperature effects on gas solubility, $PaCO_2$ and PaO_2 will be underestimated in a febrile patient and overestimated in hypothermia.[25] The need to make a correction for core body temperature currently lacks consensus and is generally not standard practice. While values are minimally affected within the ranges of 35–39°C,[26] an adjustment should be considered in cases of significant hypo- and hyperthermia.[27]

Operators should have a basic knowledge of the expected normal and abnormal responses for each testing condition to be able to identify any potential errors and to escalate potentially critical results. While there may be some age-related effects (a decline in PaO_2 with advanced age),[25] the expected healthy normal ranges at rest, breathing room air at mean sea level, during a flight simulation and shunt study are presented in Table 3.[27]

Table 3 Healthy reference range at rest, breathing ambient air at mean sea level

pH	7.35–7.45[26]
Partial pressure of oxygen (PaO_2)	80–98 mmHg[27]
Partial pressure of carbon dioxide ($PaCO_2$)	35–45 mmHg[26]
Bicarbonate (HCO_3^-)	22–26 mmol/L[27]
Base excess (BE)	−2 to +2 mmol/L[27]
Haemoglobin (Hb)	12–16 g/dL[26]
Alveolar-arterial oxygen tension gradient ($P[A\text{-}a]O_2$)	5-20 mmHg[25]
Partial pressure of oxygen breathing 15% oxygen	58 ± 4 mmHg[35]
Calculated shunt breathing 100% oxygen (Q_S/Q_T)	<8.3%[36]

Competency assessment

The standardisation of ABG sampling procedure has been shown to improve significantly puncture success rate, reduce patient-reported discomfort and maximise result accuracy.[28]

Training and assessment of competency should be documented and cover minimum prerequisite knowledge that includes[2,29]:

- Relevant anatomy and site selection
- Indications, contraindications and potential complications
- Strategies to increase success rate and minimise risk of discomfort
- Preparation, collection and post-sample handling procedure
- Factors that can lead to sample analysis inaccuracies
- Normal and abnormal results under varying ambient and metabolic conditions.

A period of observation of correct clinical sampling technique is then directly followed by supervised sampling utilising a competency checklist with feedback discussion. While there is no standardised number of observations or supervised samples, it is important that both the supervisor and the trainee be comfortable to progress to unsupervised sampling. A suggested operator competency assessment form is provided in Supporting Information 1. Ongoing annual operator competency assessment allows for managerial audits of service quality and ensures continued patient safety.

Conclusion

The assessment of gas exchange is the hallmark of respiratory medicine, and ABG sampling aligns with the medical scientist's scope of practice. This novel position statement utilises available evidence to improve the puncture success rate and to minimise both sampling and analysis errors. Invasive procedures create patient reluctance, with known increases in patient anxiety with frequent and repetitive ABG sampling. With adherence to the presented standardised procedure and competency assessment, operator confidence will be augmented, and patient discomfort and, thus, reluctance for repeat testing will be minimised.

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Supporting Information

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