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After 2 years as a nursing groom at Liphook Equine Hospital, Sarah relocated to Aberdeenshire and worked at Ardene House Veterinary Hospital where she qualified as an REVN and became head equine nurse. Sarah subsequently completed the RCVS diploma in advanced veterinary nursing and went on to obtain a BSc (honors) and was awarded the Robert Allen memorial award for her dissertation on skin preparation for joint injection. While at Ardene House, Sarah developed an interest in equine internal medicine and in particular, equine neonatal intensive care. She also worked two stud seasons as a neonatal intensive care nurse at Scone Equine Hospital in Australia, and a season each at Hagyard Equine Medical Institute in Kentucky and Rossdales Equine Hospital in Newmarket. Sarah is now an internal medicine nurse responsible for the ICU at Rainbow Equine Hospital in North Yorkshire.

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Utilising arterial blood gas analysis in the sick equine neonate

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ABSTRACT: Arterial blood gas analysis is an important diagnostic tool in the management of sick equine neonates. Interpreting results and understanding their relevance is a useful skill for any nurse undertaking care of neonates. Relevant up to date research is scarce, meaning information often has to be extrapolated from small animal and human medical research and applied to equine patients. However, with a structured and methodical approach to interpretation, results can be effectively utilised to tailor care and improve outcomes.

KEYWORDS: Equine; neonate; foal; arterial; blood; gas; analysis

Indication for blood gas analysis

Hypoxic ischaemic encephalopathy is the most commonly encountered condition of foals within 72 hours of birth (Aleman, et al, 2013). Hypoxia leads to hypothermia, weakness, alteration in state of consciousness including seizures, lack of affinity for the mare and lack of nursing leading to starvation and hypoglycaemia (Diesch & Mellor, 2013). Therefore, hypoxia must be identified and addressed as soon as possible and the effectiveness of interventions to return the foal to a normoxic state should be evaluated frequently.

Sepsis is a very common cause of morbidity and mortality in equine neonates and both metabolic and respiratory acidosis have a high incidence in septic foals (Sanchez, 2005). Monitoring arterial blood gases allows identification of acidaemia and correction in order to prevent development of seizures, myocardial depression and organ failure.

Dystocia can also lead to metabolic acidosis, hypercapnia and hypoxia immediately after birth (Kimura, Aoki, Chiba, & Nambo, 2017). Therefore, routine blood gas analysis is indicated in all foals delivered by assisted delivery or caesarean or those which have experienced a delay in delivery.

Sample collection

While some values can be accurately ascertained from either venous or arterial blood only an arterial sample can provide an accurate partial pressure of oxygen (PaO_2) value (Malatesha, et al., 2007). In the equine neonate, arterial blood samples are commonly collected from the dorsal metatarsal artery or the median artery.

Arterial blood samples should be collected in a heparinised syringe or commercial microsampler (Figure 1). It is uncommon to be able to externally visualise an artery so palpation is the most reliable method of locating a suitable site. The hair over the intended puncture site should be removed with clippers and the area should be cleaned of gross contamination. In reactive foals it may be beneficial to apply a topical anaesthetic preparation especially when collecting a sample from the dorsal metatarsal artery.

The dorsal metatarsal artery is found on the lateral side of the hind cannon and can be palpated from distal hock to mid cannon. The needle should be inserted at a slight (approximately 10°) angle to the limb and pointed proximally towards the hock and advanced gently (Figure 2).

The median artery is found on the medial aspect of the proximal radius caudal to the cephalic vein in the mid antebrachium. The needle should be inserted at a 90° angle to the limb directly down onto the artery (Figure 3).

Normal values for arterial blood gases from healthy foals will vary dependant on age (Table 1).

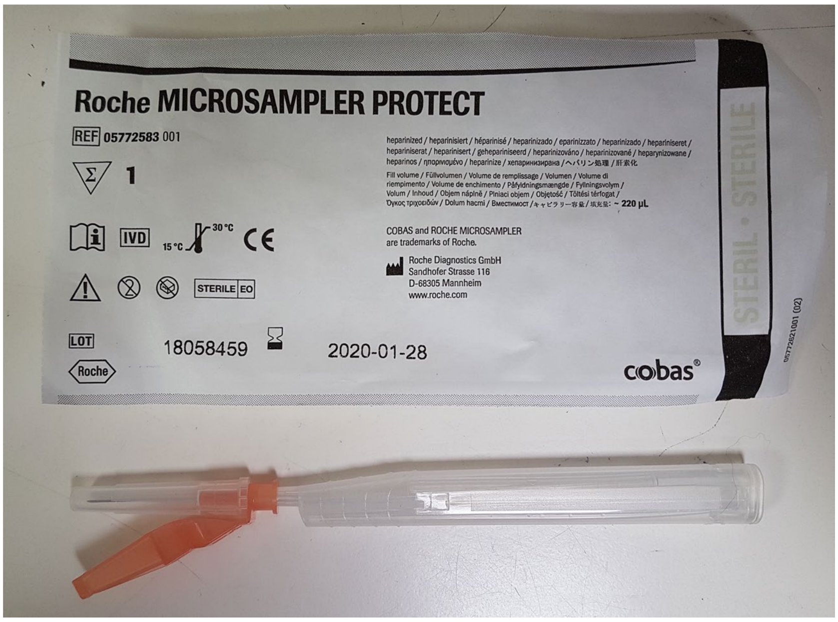

Figure 1. Microsampler.

Figure 2. Arterial sampling from the dorsal metatarsal artery.

Figure 3. Arterial sampling from the median artery of the forelimb.

Oxygen saturation (SaO_2) and partial pressure of arterial oxygen (PaO_2)

Oxygen saturation measures the amount of oxygen bound to haemoglobin in the blood and as such the amount of oxygen available to metabolising tissues. SaO_2 measures the percentage of haemoglobin that is fully saturated with oxygen.

Partial pressure describes the pressure of an individual gas, within a mixture of gases and allows assessment of the number of molecules of a particular gas within a mixture of gases (Collins, et al., 2015).

At low levels, a small drop in PaO_2 results in a large decrease in SaO_2. This justifies regular monitoring of both values to allow oxygen supplementation to be adjusted appropriately and promptly.

The relationship between PaO_2 and SaO_2 is not linear or direct even within an individual patient and this is demonstrated by the sigmoid shape oxygen-haemoglobin dissociation curve (Collins et al., 2015). When an oxygen molecule binds to haemoglobin this causes a change in conformation which allows greater affinity for binding further oxygen molecules and this increases with each additional oxygen molecule. Factors such as low pH and increased $PaCO_2$ cause a right shift in the curve meaning less affinity for binding oxygen to haemoglobin. Conversely a left shift is caused by increased pH and decreased $PaCO_2$.

PaO_2 is affected by lung health for example displaced rib fractures may cause oedema, haemorrhage and necrosis of the underlying lung meaning it becomes poorly compliant and inefficient in gaseous exchange therefore decreasing PaO_2 (May, Hillerman, & Patil, 2016)

PaO_2 demonstrates the oxygenation level of the patient while partial pressure of arterial carbon dioxide ($PaCO_2$) shows the state of ventilation. The two values should be assessed in combination for accurate interpretation.

Partial pressure of arterial carbon dioxide ($PaCO_2$)

Carbon dioxide is a by-product of all metabolic processes and is expelled from the body via the lungs. Carbon dioxide is acidic and so if the respiratory system is not functioning as it should be and carbon dioxide is not expelled from the body efficiently then a build-up can decrease the patient's pH. However, this may be counteracted by metabolic alkalosis meaning no change in pH is seen. Increased $PaCO_2$ indicates respiratory dysfunction (Diesch & Mellor, 2013).

Hydrogen ion concentration (pH)

pH refers to the scale measuring concentration of free hydrogen ions in a solution. The more acidic a solution the greater the number of free hydrogen ions and lower the pH. pH is controlled in two ways, excretion of acids and buffering. Hydrogen ions are excreted via the kidneys and carbon dioxide (a respiratory acid) is excreted via the lungs. Extracellular buffers include bicarbonate and plasma proteins and intracellular buffers include phosphate and haemoglobin.

An increased pH demonstrates alkalaemia and a decreased pH shows acidaemia. When examined with other blood gases it is possible to tell if this is respiratory driven, metabolic or both. Metabolic acidosis occurs when buffers and acid excretion are compromised and acid continues to be produced and builds up. Respiratory acidosis occurs when excretion of carbon dioxide is inhibited due to impaired ventilation.

As $PaCO_2$ is a respiratory acid, if pH is decreased and $PaCO_2$ is increased this indicates respiratory acidosis and conversely if pH is increased and $PaCO_2$ is decreased this indicates respiratory alkalosis (Waddell, 2012). pH in combination with bicarbonate and base excess is used to determine metabolic disturbances. A decrease in pH

Table 1. Normal values for arterial blood gases from healthy foals in lateral recumbency.

	2 hours of age		7 days of age	
	Value	Range	Value	Range
PaO_2 (mmHg)	66.5	+/- 2.3	86.9	+/- 2.2
$PaCO_2$ (mmHg)	47.7	+/- 1.7	46.7	+/- 1.1
SaO_2	70-100%		93-100%	
pH	7.362	+/- 0.012	7.374	+/- 0.014
HCO_3 mmol/L)	25.0	+/- 0.9	25.6	+/- 0.8
BE (mmol/L)	0.9	+/- 1.0	1.4	+/- 0.9

(Stewart, Rose, & Barko, 1984, Cruz, et al., 2015).

combined with a base deficit and low bicarbonate indicates metabolic acidosis and an increased pH combined with a high bases excess and high bicarbonate indicates metabolic alkalosis.

While the body utilises many methods of maintaining pH it will not normally overcompensate so an acidosis will not become an alkalosis due to the body's methods of homeostasis.

Bicarbonate (HCO_3)

Bicarbonate is a renally produced buffer utilised by the body to maintain pH. Initially in respiratory acidosis bicarbonate levels will be low as it is used up by the body attempting to regulate pH. Over time in chronic acidosis the kidneys will respond and increase retention of bicarbonate to cope with demand. Therefore, initially bicarbonate readings will be low but gradually increase through the normal range and potentially above normal range.

Base excess (BE)

BE describes the amount of base which would be required to be added or subtracted to return the pH to normal. A decreased BE is indicative of metabolic acidosis and conversely increased BE indicates metabolic alkalosis.

Factors affecting results

Samples need to be collected in a heparinised receptacle as use of an alternative anticoagulant or a syringe without anticoagulant will adversely affect result. Alternative anticoagulants such as EDTA and citrate are acidic and would lower pH of the sample. Liquid heparin will dilute the plasma in the sample, altering the PaO_2 result, therefore dry heparin is recommended (Sood, Paul, & Puri, 2010). The correct sample size for the amount of heparin should be collected and the sample should be mixed thoroughly to prevent coagulation. Care must be taken to avoid mixing venous and arterial blood during sample collection as this will generate a falsely low PaO_2 result. Any air bubbles present in the sample at collection must be expelled immediately to avoid adversely altering the PaO_2 result. Samples should be analysed within 15 minutes of collection or significant decreases in PaO_2 and increases in $PaCO_2$ readings may be seen (Srisan, et al., 2011).

Changes in patient position have a direct effect on blood gas results and foals sampled standing have PaO_2 values around 14 mmHg higher than foals sampled in lateral recumbency (Stewart et al., 1984). It is rarely practical to collect arterial blood samples from a standing foal and restraint of a neonate is best done in lateral recumbency to allow access to arterial puncture sites. But as long as serial samples are collected in the same position and patient position is taken into account when interpreting results then collection from foals restrained in lateral recumbency is acceptable.

Respiratory rate should be taken into account when interpreting results as $PaCO_2$ may be within normal limits in a foal which is hypoxaemic but hyperventilating (Diesch & Mellor, 2013).

Appropriate nursing interventions to positively affect results

In a recumbent foal, maintaining a sternal position is essential to allow optimal respiratory function. This will positively affect oxygenation and the success of this nursing intervention can be determined by serial monitoring of respiratory blood gases such as PaO_2.

Supplemental oxygen provision for hypoxic foals is an important nursing intervention and monitoring of respiratory blood gases to assess its effect is important. Hyperoxia can trigger vasoconstriction and reduction in cardiac output thus reducing oxygen delivery to the tissues therefore supplemental oxygen should be reduced when PaO_2 is higher than 100 mmHg.

When providing supplemental oxygen or if mechanical ventilation is utilised this should be maintained in a way that prevents the patient from rebreathing expelled gases which would cause an increase in $PaCO_2$. It is also important to control pain and minimise stress to the patient as these factors can cause hyperventilation leading to respiratory alkalosis.

Healthy kidneys facilitate removal of filtered acids from the body, compensate for respiratory acid/base disturbances and correct metabolic disturbances therefore effective renal function is essential for maintaining arterial blood gas parameters. Urine output should be closely monitored and recorded to ensure signs of renal disfunction are noticed.

The provision of appropriate intravenous fluid therapy and correct nutrition can not only support renal function but also replace gastrointestinal losses. Bicarbonate may be lost through diarrhoea or reflux so it is useful to measure these in order to estimate losses and replace them.

Conclusion

Arterial blood gas analysis is a vital tool in gold standard treatment of sick equine neonates and is something a nurse working in a neonatal intensive care unit can grasp a good understanding of. A methodical approach to arterial blood gas analysis interpretation can help simplify understanding and make interpretation less intimidating. Being able to identify abnormal results and understand the mechanisms behind these abnormalities means appropriate interventions can be put in place promptly and patients receive the best care possible.

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Multiple Choice Questions

1. **Which parameter can only be accurately assessed via arterial sample?**
   - (a) PO_2
   - (b) PCO_2
   - (c) pH
   - (d) HCO_3

2. **Which anticoagulant is appropriate for sample collection?**
   - (a) Citrate
   - (b) EDTA
   - (c) Fluoride oxalate
   - (d) Heparin

3. **Which nursing intervention does NOT positively affect ABG results?**
   - (a) Supplemental oxygen provision
   - (b) Provision of appropriate fluid therapy
   - (c) Maintaining lateral recumbency
   - (d) Provision of appropriate nutrition

4. **What does $PaCO_2$ relate to?**
   - (a) State of ventilation
   - (b) Oxygenation level
   - (c) Amount of oxygen bound to haemoglobin
   - (d) Hydrogen ion concentration

For the answers to the MCQs, please go to: **http://www.bvna.org.uk/publications/veterinary-nursing-journal**