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REVIEW

Easy blood gas analysis: Implications for nursing

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KEYWORDS

Arterial blood gases;
Arterial puncture;
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Acid base imbalance;
Oxyhaemoglobin Dissociation Curve

Abstract Arterial blood gas analysis is a common investigation in emergency departments and intensive care units for monitoring patients with acute respiratory failure. It also has some applications in general practice, such as assessing the need for domiciliary oxygen therapy in patients with chronic obstructive pulmonary disease. An arterial blood gas result can help in the assessment of a patient's gas exchange, ventilatory control and acid–base balance. Nurses are usually involved in taking and analyzing the ABGs and normally they report these results to the doctors or anesthesiologists. Out of these results the anesthesiologists will then prescribe further treatment for the critically ill patient. Hence, it is important that nurses are familiar with the information obtained to be able to detect the disturbances in ventilation, oxygen delivery and acid–base balance.

Contents

Abbreviations ABGs, arterial blood gases; ODC, Oxyhaemoglobin Dissociation Curve

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Introduction

Arterial blood gas analysis is a common investigation in emergency departments and intensive care units for monitoring patients with acute respiratory failure. It also has some applications in general practice, such as assessing the need for domiciliary oxygen therapy in patients with chronic obstructive pulmonary disease. An arterial blood gas result can help in the assessment of a patient's gas exchange, ventilatory control and acid–base balance [1]. However, the investigation does not give a diagnosis and should not be used as a screening test. It is imperative that the results are considered in the context of the patient's symptoms. While non-invasive monitoring of pulmonary function, such as pulse oximetry, is simple, effective and increasingly widely used, pulse oximetry is no substitute for arterial blood gas analysis [2,3]. Pulse oximetry is solely a measure of oxygen saturation and gives no indication about blood pH, carbon dioxide or bicarbonate concentrations [4].

The arterial blood gas (ABG) is frequently used for monitoring the patient's respiratory status and ABGs can be sampled as an arterial stab or by drawing blood from an arterial line. Knowledge about interpretation of ABGs is consequently essential for nurses who are working in ICU, to be able to analyze each component of the ABGs to avoid overlooking a change that could result in an inaccurate interpretation and lead to inappropriate treatment. All over the world nurses in ICU use considerable time in drawing, documenting, reporting and interpreting blood gases. Blood gases can be obtained from the arteries, veins or capillaries [1,3].

Arterial blood gases are analyzed with a great frequency. Nurses are usually involved in taking and analyzing the ABGs and normally they report these results to the doctors or anesthesiologists. Out of these results the anesthesiologists will then prescribe further treatment for the critically ill patient. Hence, it is important that nurses are familiar with the information obtained to be able to detect the disturbances in ventilation, oxygen delivery and acid–base balance [5].

Arterial puncture

Blood is usually withdrawn from the radial artery as it is easy to palpate and has a good collateral supply. The patient's arm is placed palm-up on a flat surface, with the wrist dorsiflexed at 45°. A towel may be placed under the wrist for support. The puncture site should be cleaned with alcohol or iodine, and a local anesthetic (such as 2% lignocaine) should be infiltrated. Local anesthetic makes arterial puncture less painful for the patient and does not increase the difficulty of the procedure. The radial artery should be palpated for a pulse, and a pre-heparinized syringe with a 23 or 25 gauge needle should be inserted at an angle just distal to the palpated pulse (Fig. 1) [6]. A small quantity of blood is sufficient. After the puncture, sterile gauze should be placed firmly over the site and direct pressure applied for several minutes to obtain hemostasis. If repeated arterial blood gas analysis is required, it is advisable to use a different site (such as the other radial artery) or insert an arterial line. To ensure accuracy, it is important to deliver the sample for analysis promptly [7]. If there is any delay in processing the sample, the blood can be stored on ice for

Figure 1 Performing an arterial puncture.

Table 1 Indications for arterial blood sampling/analysis.

Indications for arterial blood sampling/analysis
• Collapse of unknown cause
• Respiratory distress — hypoxia
• Titration of artificial ventilation
• Altered level of consciousness
• Poisons/toxin ingestion
• Metabolic disorders — diabetic ketoacidosis
• Trauma — management of raised intracranial
• Pressure
• Shocked patient — sepsis, cardiogenic
• Evaluation of intervention – fluid resuscitation
• Inotropic therapy

approximately 30 min with little effect on the accuracy of the results. Complications of arterial puncture are infrequent. They include prolonged bleeding, infection, thrombosis or arteriospasm [2,8].

When an ABG analysis is needed

The common indications for ABGs are included in Table 1 [4]. Analysis of arterial blood can assist in the assessment of the patient's respiratory and metabolic systems. However, it should not be relied on in isolation when making clinical decisions: a thorough systematic clinical assessment of the patient with regular re-evaluation can be far more beneficial than the information obtained from a single arterial blood gas result [7].

Physiology of ABGs

The components of an ABG analysis are PaO_2, SaO_2, hydrogen ion concentration (pH), $PaCO_2$, HCO_3^-, base excess, and serum levels of hemoglobin, lactate, glucose and electrolytes (sodium, potassium, calcium, and chloride). Because HCO_3^- and base excess both yield similar information on the status of base (alkali), I'll only discuss HCO_3^-. The parameters most frequently used—PaO_2, SaO_2, pH, $PaCO_2$, HCO_3^-, and lactate—often are adequate in diagnosing and managing most clinical situations. The normal values of ABG are discussed in Table 2 [9].

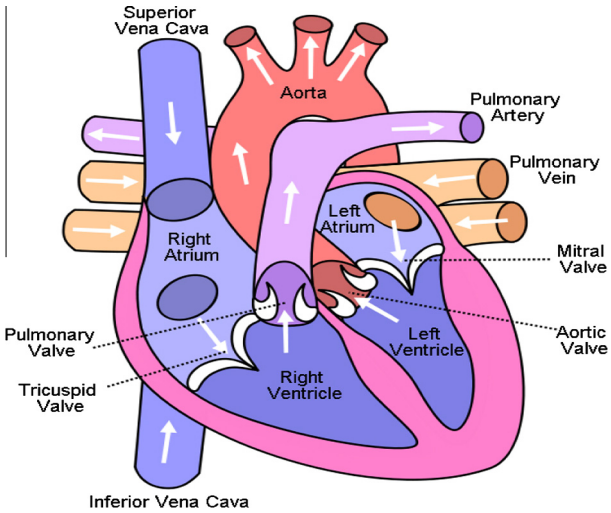

Figure 2 The heart above shows where our subclavian central lines sit – in the superior vena cava; it is here we can take venous blood gases. Samples from the pulmonary artery are however, more accurate and can only be performed if the patient has a PA catheter.

Types of blood gasses

Arterial blood gas

The arterial blood may be sampled from a single stab which can be done from the femoral, brachial or radial artery [2,3].

Table 2 Normal values and Definitions.

Name	Definition	Value
PH	Refers to hydrogen ion (H+') levels, hence the 'H' in pH. H+ levels are important because a lack of (deficit) or too much (excess) will tell you if the patient is acidotic or alkolotic. One confusing point about pH is that it is an INVERSE ratio, which means that the more H+ present, the lower the pH and vice versa	7.35–7.45
Acid	Can give away an H+ or can separate (dissociate) hydrogen from its ion, so the hydrogen is not positive and therefore no longer an acid Acids are end products of metabolism and must be buffered or excreted to achieve a normal pH	20 parts base/ 1 part acid
Base	Unlike Acids, bases can accept a H + and bond with hydrogen. They are all negative and like to 'buffer' body acids.	
Base excess/ base deficit	Represents an increase or decrease in the amount of base compared with the amount of acids present	−2 to + 2 mmol/L
HCO_3^-	Concentration of hydrogen carbonate in blood. Used to determine along with pH and CO_2 source of acid base imbalance	22–26 mmol/L
pCO_2	Carbon dioxide partial pressure (tension). Reflects alveolar ventilation as it diffuses across the alveolar capillary membrane and "blown off"	35–45 mmHg
paO_2	Arterial oxygen tension. In other words how well the lungs are able to pick up oxygen, i.e. supply, but not demand	75–100 mmHg
Lactate (lactic acid)	When cells no longer have enough O2 for 'normal' aerobic metabolism (cell hypoxia) Anaerobic metabolism takes over resulting in lactate production, leading to lactic acidosis	0.5–2.0 mmol/L
Hb (hemoglobin)	Amount of hemoglobin in blood possibly capable of carrying oxygen	135–180 g/L 7

Table 3 Arterial versus venous blood gases.

Value	Arterial blood	Mixed venous
pH	7.40 (7.35–7.45)	7.36 (7.31–7.41)
PaO_2	80–100 mmHg	35–40 mmHg
O_2 saturation	95%	70–75%
$PaCO_2$	35–45 mmHg	41–51 mmHg
HCO_3^-	22–26 $mEqL^{-1}$	22–26 $mEqL^{-1}$
BE	−2 to +2	−2 to +2

(Table adapted from [3]); O_2: oxygen, PaO_2: partial pressure of oxygen in arterial blood, pH: acidity/alkalinity, $PaCO_2$: partial pressure of oxygen in arterial blood, HCO_3^-: bicarbonate in blood, BE: base excess.

This stab may result in spasm, intraluminal clotting, bleeding or temporary obstruction which may influence these arteries' blood supply. The collateral arterial blood may provide this supply however, the brachial and femoral arteries do not have adequate collateral supplies. Hence, the preferably arterial puncture site is the wrist at radial artery [4].

According to Coggon [4] the safest site for the arterial cannula is the radial artery due to the fact that the cannula can be easily and closely observed. ABGs sampled from a permanent arterial line is yet considered painless and the simplest way in obtaining blood sample [10]. Problems may be encountered in extracting blood from the arterial line like bleeding, infection and vessel obstruction. Blood gas sample obtained from a permanent arterial line provides the most efficient assessment of the pO_2 and pCO_2 in the body and gives much more insight into effective ventilation [1,5].

Venous blood gas

Venous blood gas (VBG) is sampled from the central venous line or from a venipuncture in the patients arm and is rarely analyzed. However, in cases like sepsis, shock, and fever congestive heart failure where there is impaired circulation it is essential to assess mixed venous oxygen saturation. Mixed venous blood is blood from all organs of the body and it is only sampled from the pulmonary artery (Fig. 2) [11] and is hardly ever analyzed in the ICU. The blood gas components' value from mixed venous blood and arterial blood is nearly the same except for oxygen pressure (pO_2) and saturation (SO_2). The wide range of oxygenation values between arterial and venous blood is the reason why the peripheral venous blood is never used to measure the patient's status of oxygenation, Table 3 [6].

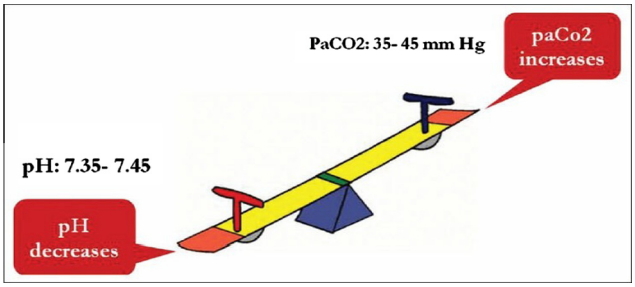

Figure 3 Visualization of pH and pa CO_2.

Figure 4 Visualization of pH and bicarbonate as an elevator.

Capillary blood gas

Obtaining samples from the capillaries is less complicated than from the veins or the arteries. In general the capillary blood gas (CBG) will provide nearly the same results as the ABG [10]. However capillary samples give inaccurate results in cases where there is vasoconstriction, for example in patients who are hypothermic [9]. Blood gases sampled from the capillary is often done in newborns and children to avoid excessive blood loss and it is easier to obtain [12]. CBG can be taken from heel of the infants and from the fingertips of children. For adults, capillary blood gases can be taken from the earlobes [2]. There is a major correlation in pH, pCO_2, pO_2, BE and HCO_3 among ABG, VBG, and CBG values, except for a reduced correlation in pO_2 in the presence of hypotension [1] and poor systemic perfusion. CBG can be an alternative for ABG for gasometric evaluation for children even though if the patient is hypothermic or poorly perfused, as long as the patient is not hypotensive. ABG samples drawn from a permanent arterial line will provide the nurses with the most reliable result of pO_2 and pCO_2 [13].

Basic facts to remember

1. CO_2 is a respiratory component and considered a respiratory acid. It moves opposite to the direction of pH and is visualized as a see-saw (Fig. 3) (as $paCO_2$ in blood increases, pH decreases—respiratory acidosis) [4].
2. Bicarbonate is a metabolic component and considered a base. It moves in the same direction as pH and is visualized as an elevator (Fig. 4) (as bicarbonate in blood increases, pH increases—metabolic alkalosis) [4].
3. If CO_2 and HCO_3^- move in the same direction, it is considered a primary disorder; for example, if there is respiratory acidosis in the body (CO_2 retention), the bicarbonate levels increase as a compensation (metabolic alkalosis). The directions of both CO_2 and HCO_3^- are the same in this case [6].
4. If CO_2 and HCO_3^- move in opposite directions, it is considered a mixed disorder; for example, mixed disorder in the case of salicylate poisoning: primary respiratory alkalosis due to salicylate-induced hyperventilation and a primary metabolic acidosis due to salicylate toxicity [3].

Acid–base balance

Acid–base balance is a reflection of the pH level. The pH is the measurement of the acidity or alkalinity of any fluid and is

recorded on a scale from 1 (very acidic) to 14 (very alkalotic). A fluid with a pH of 7 (water) is considered neutral. The pH of blood falls within a narrow range of 7.35–7.45. This range is essential for the body systems to function properly. Mechanisms are in place to ensure that a constant state of acid–base equilibrium exists within the blood at all times. Significant alterations from this range can interfere with cellular functioning and ultimately, if uncorrected, death. Therefore, it is essential that nurses recognize when a patient is not able to maintain this delicate balance, and intervene appropriately [1,7,14].

Measuring pH

To quantify the H+ concentration in blood, a simplified mathematical expression, called pH, is used. In health, the normal range for pH is 7.35–7.45 (Box 2). PH is a negative logarithm, which means that the higher the H+ concentration, the lower the pH and vice versa [5].

Maintaining acid–base balance

The three systems that regulate the acid–base balance are the buffer system (metabolic), kidneys (metabolic) and the lungs (respiratory) [1]. The lungs regulate carbon dioxide (CO_2) and the renal system regulates bicarbonate (HCO_3), one of the body's buffers. Therefore, to maintain the tight balance both the respiratory and metabolic system work together in an attempt to compensate for any abnormalities [11].

Oxygenation

Determination of oxygenation should be included in any physical assessment. When assessing ventilation status, it is important to look at the PaO_2 and SaO_2 levels. The PaO_2 represents the amount of oxygen dissolved in the blood. A normal value for arterial blood gas is 80–100 mmHg. The SaO_2 represents the amount of oxygen bound to hemoglobin. A normal SaO_2 value for arterial blood gas is 95–100%. It is also important to note that assessment of ABGs includes determining the need for and treatment of pulmonary disease and determining acid–base balance in a patient with heart failure, renal failure, uncontrolled diabetes, a sleep disorder, severe infection, and drug overdose [12].

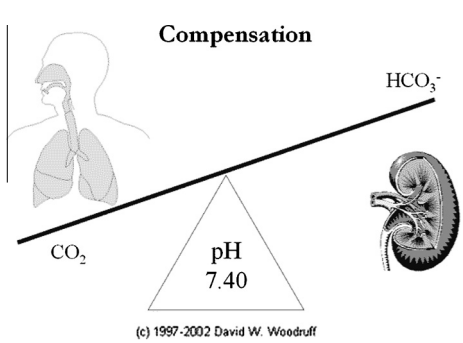

Figure 5 The respiratory and renal systems to maintain the pH level.

Table 4 Acid–base disorders.

Increased CO_2 (>40 mmHg)	Respiratory acidosis
Decreased CO_2 (<40 mmHg)	Respiratory alkalosis
Increased HCO^{3-} (>24 mEqL/L)	Metabolic alkalosis
Decreased HCO^{3-} (<24 mEqL/L)	Metabolic acidosis

Buffers

The body has two buffer systems in place to maintain the pH level with its narrow range: the respiratory and renal systems [4].

Respiratory buffer

A normal by-product of cellular metabolism is carbon dioxide (CO_2). CO_2 is carried in the blood to the lungs, where the excess combines with water to form carbonic acid. The pH of the blood will change according to the amount of carbonic acid present. The more carbonic acid present in the blood, the lower (more acidic) the pH level will become. In response, the lungs will either increase or decrease the rate and depth of ventilation until balance is restored. This process occurs within 1–3 min in a healthy individual [1,6].

Renal buffer

The renal system acts as a buffer through its ability to excrete or retain bicarbonate (HCO_3). Bicarbonate is considered alkaline and although takes a little longer than the respiratory system to respond, is considered a powerful buffer. As the blood pH decreases (more acidic), the kidneys will compensate by retaining HCO_3 and likewise, as the blood pH increases, the kidneys excrete HCO_3 [11].

When the lungs and kidneys are working together, they are able to maintain the pH of the blood within its narrow range of 7.35–7.45. It is when one or both of these buffer systems fail that the patient's status is compromised reflecting in abnormal arterial blood gases. The earlier such compromise is detected, the more likely an appropriate intervention can successfully restore equilibrium (Fig. 5) [13].

Acid–base imbalance

Respiratory acidosis

Respiratory acidosis is defined as a pH less than 7.35 with a $PaCO_2$ greater than 45 mmHg (Table 4) [15]. Acidosis is primarily caused by an accumulation of CO_2 through the production of carbonic acid. Any condition that results in hypoventilation can cause respiratory acidosis by preventing the exhalation of CO_2 [9]. These conditions include: central nervous system depression related to trauma, narcotics, sedatives or anesthesia impaired respiratory muscle function related to spinal cord injury, neuromuscular disease or blocking agents pulmonary disorders such as atelectasis, pneumonia, pneumothorax, embolus, pulmonary edema or obstruction hypoventilation related to pain, chest wall injury or abdominal distention.

If CO_2 levels become extremely high, drowsiness and unresponsiveness may be noted. Increasing ventilation and

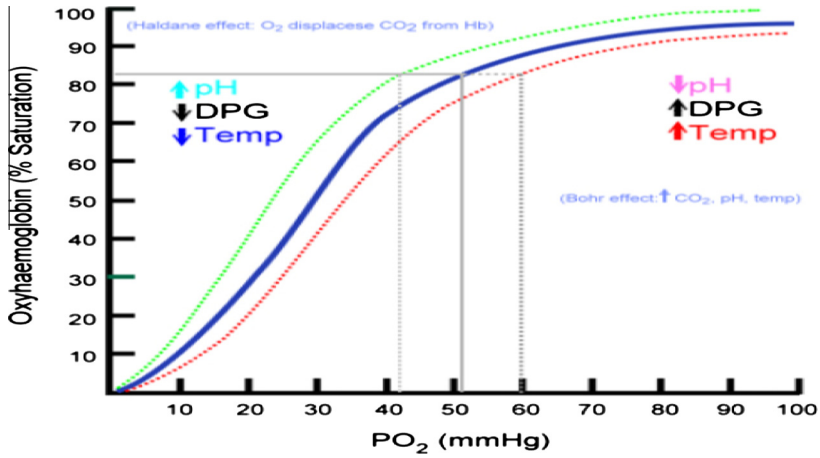

Figure 6 Oxyhaemoglobin Dissociation Curve (ODC).

treatment of the underlying cause will correct respiratory acidosis [16].

Respiratory alkalosis

Respiratory alkalosis is defined as a pH greater than 7.45 with a $PaCO_2$ less than 35 mmHg. Any condition that causes hyperventilation can result in respiratory alkalosis. These conditions include: psychological responses such as anxiety, severe stress or fear unresolved pain increased metabolic demands such as fever, sepsis, or pregnancy central nervous system lesions [1,7].

Metabolic acidosis

Metabolic acidosis is defined as a pH of less than 7.35 and a bicarbonate level less than 22 mEq/L. It is caused by either a deficit of base in the bloodstream or an excess of acids, other than CO_2. Causes of metabolic acidosis include: renal failure, diabetic ketoacidosis, anaerobic metabolism, starvation and salicylate intoxication [4].

Metabolic alkalosis

Metabolic alkalosis is defined as a pH of greater than 7.45 and a bicarbonate level greater than 26 mEq/L. An excess of base or a loss of acid within the body can lead to metabolic alkalosis. Causes include: protracted vomiting, aggressive gastric suctioning and excess administration of diuretics [11,16].

Oxyhaemoglobin Dissociation Curve (ODC)

The ODC looks at the relationship between oxygen tension (pressure) and oxygen saturation (Fig. 6) [10]. It helps us better

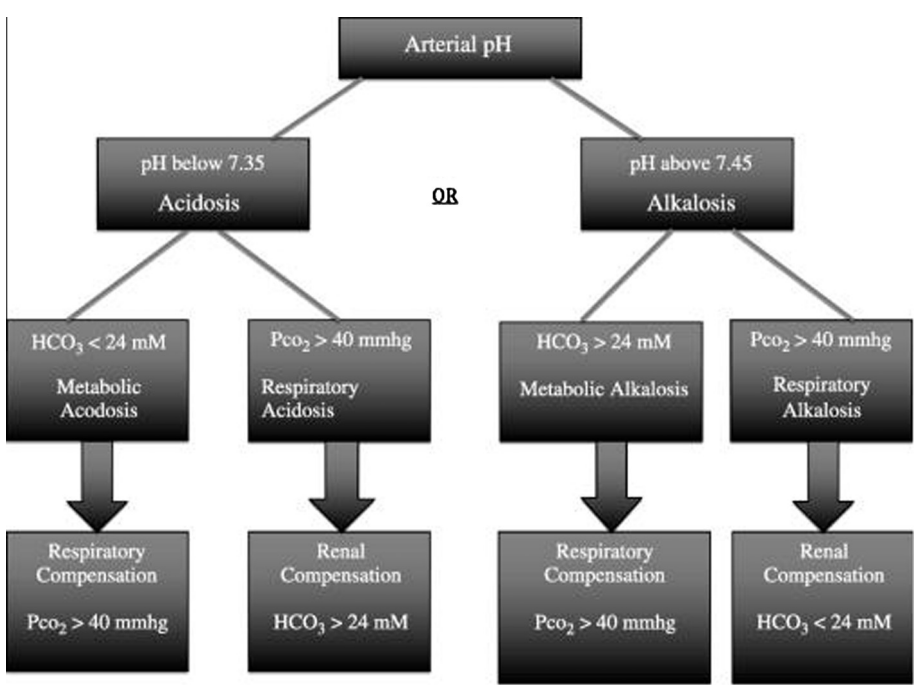

Figure 7 Stepwise approach to interpreting ABGs starting with pH.

understand how our blood interacts with oxygen, i.e. how and why it picks up and lets oxygen go.

Right shift (acidosis)

Shift of the curve to right decreases affinity-meaning that the Hb is not very attracted to oxygen, and when it does pick up oxygen, it lets it go very quickly.

Left shift (alkalosis)

Shift of the curve to the left increases affinity-meaning that the Hb is very attracted to oxygen and when oxygen is picked up, the Hb has a hard time letting it go at the cellular level.

Ways to interpret ABG

It is essential that nurses thoroughly interpret each component of the ABGs to avoid overlooking any change in the patient's respiratory status that could lead to inappropriate or inaccurate treatment [16]. Below there is outlined a four step guideline to help pediatric intensive care nurses systematically interpret the ABG results [17].

1. Assess oxygenation, low pO_2 and SO_2 indicate inadequate supply of oxygen and high pO_2 and SO_2 indicate adequate supply of oxygen [4].
2. Determine the pH and any irregularity (alkalosis or acidosis) Fig. 7 [9]. The rate and depth of breathing can change the pH in minutes.
3. Determine the causes of irregularity either respiratory (irregularity of pCO_2) or metabolic (irregularity of HCO_3) [17].
4. Determine the compensatory mechanism for example in case of respiratory acidosis whereby there is low pH and increased pCO_2 and this is fully compensated by the kidney mechanism. In cases where there is metabolic acidosis, bicarbonate deficit and decreased pH, the lung compensation mechanism is used by increasing the rate and depth of respiration. For example in mechanically ventilated patients the respiratory rate and tidal volume are increased [7]. In addition it is greatly important to have an idea of the full clinical history of the patient in interpreting blood gas. For example pO_2 and SO_2 are related to the amount of oxygen administered to the patient as well as hemoglobin concentration. Serum electrolytes are to be considered also in interpretation especially when making nursing diagnosis with its correspondent nursing treatment [18].

When your patient is on mechanical ventilation

Mechanical ventilation aims to improve oxygenation and ventilation. In a mechanically ventilated patient, ABGs can guide clinicians in titrating ventilator support and weaning. Person's minute ventilation (respiratory rate multiplied by tidal volume [VT]) controls the elimination of CO_2 and, consequently, affects the levels of $PaCO_2$ and pH. With volume control ventilation, the preset respiratory rate and VT determine minute ventilation. For pressure control ventilation, minute ventilation is influenced by the preset inspiratory pressure, respiratory rate, inspiratory time, respiratory resistance, and lung compliance. Pressure support ventilation increases spontaneous VT and, therefore, is commonly prescribed for synchronized intermittent mandatory ventilation (SIMV), pressure support ventilation, and other modes, to lower $PaCO_2$ for patients who have spontaneous breaths[4,10].

ABG results should be interpreted in light of the patient's medical history, present health status, and medical therapies. When the patient's $PaCO_2$ and HCO_3^- are both abnormal, this information will help you determine if another abnormality is the result of compensation or dual pathology. Remember that full compensation or mixed respiratory and metabolic disorders can move pH in opposite directions, resulting in a normal PH. Assess and monitor your patient, and treat the underlying causes of acid–base derangement as well as correcting abnormal parameters. Monitor your patient's response to changes in ventilator settings and inform the healthcare provider as necessary [15].

Act quickly

In a critical care setting, a patient's condition can change rapidly and dramatically. Using a four-step approach to ABG interpretation can identify an acid–base disorder quickly and accurately so you can intervene appropriately. If your patient is mechanically ventilated, good ABG interpretation skills can guide clinicians in adjusting the ventilator settings to meet the patient's needs [18].

Conclusion

Measuring arterial blood gases can be a useful adjunct to the assessment of patients with either acute or chronic diseases. The results show if the patient is acidaemic or alkalaemic and whether the cause is likely to have a respiratory or metabolic component. The $PaCO_2$ reflects alveolar ventilation and the PaO_2 reflects the oxygenation of arterial blood. When combined with a patient's clinical features, blood gas analysis can facilitate diagnosis and management. All over the world nurses in ICU use considerable time in drawing, documenting, reporting and interpreting blood gases.

Conflict of interest

There is no conflict of interest.

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