MEDICAL EDUCATION SYSTEMS

Advanced Blood Gas Analysis

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Advanced Blood Gas Analysis

This course emphasizes the importance of the relationship between Arterial Blood Gas (ABG) and the abnormal physiologic process underlying cardiopulmonary dysfunction. The course will demonstrate how to perform ABG calculations and interpret the clinical significance of the results. Case studies will be presented for application of these skills.

Purpose Statement: To provide a learning experience for students to perform Arterial Blood Gas calculations, interpret the clinical significance of the results and recommend an appropriate course of action.

Learning Objectives:

Upon successful completion of this course, you will be able to:

- Relate arterial blood gas results to the abnormal physiologic processes underlying cardiopulmonary dysfunction.
- Classify the four types of acid-base imbalance according to underlying causes.
- Review the body's mechanisms of compensation for acid-base imbalance.
- Compare and contrast hypoxia and hypoxemia.
- Examine various calculations which utilize arterial blood gas results and relate their clinical significance, such as the A-a gradient, arterial oxygen content, mixed venous oxygen content and the shunt equation.
- Review case studies, interpret the results of the arterial blood gas and describe the suggested course of action.

In non-emergency medical departments such as internal medicine sampling of arterial blood and analysis for acid-base status is not routinely performed. Peripheral venous blood is routinely taken but interpretation of its acid-base status is difficult. This paper presents a method for calculation of arterial acid-base and blood gas status from measurements in peripheral venous blood combined with a pulse oximeter measurement of arterial saturation. The use of the method has been illustrated using the data of three patients with different acid-base, haemodynamic, and metabolic conditions. The sensitivity of the method has been tested for measurement errors including venous blood acid-base and blood gas status and pulse oximetry; errors due to physiological assumptions including the values of RQ and strong acid production at the tissues; and errors due to air bubbles in the blood. Errors due to these effects are relatively insignificant except for errors in calculated arterial PO(2), particularly when SpO(2) is greater than 97%; and errors when the change in base excess across the sampling site due to strong acid production is greater that 1.3 mmol/l.

Methods for Evaluating Arterial Blood Gas Results

Evaluate alveolar ventilation and its relation to changes in the alveolar oxygen and alveolar carbon dioxide tension.

• Evaluate the relation of alveolar ventilation to arterial carbon dioxide tension and carbon dioxide clearance.

• Assess changes in PaCO2 affecting arterial affecting oxygen tension (PaO2).

• Examine pH changes associated with changes in PaCO2 and bicarbonate (HCO3-.

Normals

- pH 7.35 - 7.45
- PaCO 35 - 45 mmHg
- PaO 80 - 100 mmHg
- HCO^{3} 22 – 26 mEq/L
- BE ± 2 mEq/L
- SaO^{2} 96 – 100%

vvLevels of hypoxemia will be defined as:

vvPaO 60 - 79 mmHg is mild hypoxemia.

vvPaO 40 - 59 mmHg is moderate hypoxemia.

vvPaO < 40 mmHg is severe hypoxemia

Important Point #1

Physical Correlation is a Must!!

• Blood gas values must always be examined In the light of what it takes to get that patient to that blood gas.

• Example #1

• In comparing two patients' (Patient A & Patient B) blood gas values you find they both have a PaCO2 of 40 mm Hg.

• Upon physical exam you find patient A has a minute ventilation of 5 L/m and patient B has a minute ventilation of 40 L/m.

• Do these patients have similar lung disease?

• What additional information does the physical exam provide that the blood gas values in isolation did not?

Important Point #1 Physical Correlation is a Must!! (Cont.)

• Blood gas values must always be examined In the light of what it takes to get that patient to that blood gas.

• Example #2

- In comparing two patients' (Patient A & Patient B) blood gas values you find they both have a PaO2 of 100 mm Hg.
- Upon physical exam you find patient A if on 5 L/m oxygen by nasal cannula and patient B is on 100% O2 by high flow mask.

• Do these patients have similar lung disease?
• What additional information does the physical exam provide that the blood gas values in isolation did not?

Prediction Is Key
• When using mechanical ventilation to support a life, the care giver must be able to predict the consequences of a change in ventilator settings.
• If you are guessing you are dangerous!!

Changes in PAO2 and PA CO2
Associated With Changes in Alveolar Ventilation

$V_A = \cdot f\ (V_T - V_D)$

• Normal alveolar ventilation is 4 –5 L/m.

Alveolar Ventilation, $PaCO_2$, and VCO_2

● How much CO_2 is being produced versus how well it is being removed by the lungs is described by:

$PACO_2 = VCO_2 \times 0.863 / VA$
where VA=VE-VD

• CO_2 production must be in milliliters per minute and alveolar ventilation must be in liters per minute.

Alveolar Ventilation, $PaCO_2$, and VCO_2

•Example Calculation
•What is the $PaCO_2$ when the VCO_2 is 475 is mL/min and V_A is 4.5 L/min?

$$PACO_2 = \frac{\dot{V}CO_2 \times 0.863}{\dot{V}A} = 0.863 \bullet 475/4.5$$

Changes in $PaCO_2$ Affecting PaO_2PaO2
• Alveolar Air Equation

$$PAO_2 = PIO_2 - PACO_2\left(FIO_2 + \frac{(1 - FIO_2)}{R}\right)$$

- As $PaCO_2$ rises the PAO_2 will fall and vice versa.
- Because it is assumed $PAO_2 = PaO_2$ the PaO_2 will also be reduced.
- Rule of Thumb: as the $PaCO_2$ increases by 1 mmHg, the PaO_2 will decrease by 1.25 mmHg.

Critically ill patients are not confined to critical care units. Every day, practitioners working in acute areas encounter arterial blood gas (ABG) results, which they may not necessarily be able to interpret. It can be difficult to find time to develop knowledge. However, in light of guidance and policy documents (NICE, 2007; Department of Health, 2000), it is imperative that all nurses working in acute areas can interpret ABGs and ensure patients receive timely and appropriate care.

What is an ABG?

For analysis a small sample of arterial blood (approximately 2ml) is taken from an arterial sampling device (arterial line) situated in an artery, or taken via an intermittent 'stab' into an artery. The former method is better for patients if frequent samples are required as it reduces pain and the risk of damage to the artery.

An ABG is typically requested to determine the pH of the blood and the partial pressures of carbon dioxide (PaCO2) and oxygen (PaO2) within it. It is used to assess the effectiveness of gaseous exchange and ventilation, be it spontaneous or mechanical. If the pH becomes deranged, normal cell metabolism is affected. The ABG allows patients' metabolic status to be assessed, giving an indication of how they are coping with their illness. It would therefore seem logical to request an ABG on any patient who is or has the potential to become critically ill. This includes patients in critical care areas and those on wards who 'trigger' early-warning scoring systems. Others who give cause for concern are patients with acute illnesses or exacerbations of conditions and those in the peri-operative and peri-arrest periods.

Transferring the sample to the analyser

In order for the sample to be accurate, it should be analysed within 10 minutes of sampling from the patient (Cornock, 1996). To prevent haemolysis it should be handled gently, avoiding any vigorous shaking. Providing constant agitation by rolling the syringe gently will also prevent plasma separation.

Patient details and percentage of oxygen being administered must be entered along with their identification number. Some machines request patients' core temperature as it is known to affect the gases dissolved within the plasma, and result in a more accurate reading. However, Woodrow (2004) pointed out that temperature probes can be inaccurate and so entering a temperature of 37ºC for all patients would be better practice.

Information provided by an ABG

Depending on the type of analyser, nurses may receive some or all of the following information, outlined below.

pH and hydrogen ion (H+) activity
The pH scale ranges from 1–14, where 1 is the strongest acid, 14 is the strongest alkali and 7 is neutral. Although the pH may vary slightly within a range and still be considered normal, for the purpose of ABG analysis 7.4 is considered the absolute norm (Pagana and Pagana, 2006). This reading is slightly alkalotic.

The pH of a solution gives information on the potential for it to become hydrogen. When acids are dissolved in water they release free hydrogen ions (H+). The concentration of H+ is far greater in an acid than it is in an alkali and, obviously, the stronger the acid, the more H+ it contains. It is therefore slightly confusing that something with a high potential to become hydrogen has a small number on the pH scale. The reason for this is that the scale is a negative logarithm designed to help understanding of very small numbers with many decimal places. A pH of 1 means that the concentration of H+ in that solution is 0.1. A pH of six denotes that the concentration of H+ in that solution is 0.000001 and a pH of 14 denotes an H+ concentration of 0.00000000000001. It would be impractical to keep writing down all these decimal places, so we tend to refer to the number of zeros as the pH.

For every decrease in the pH by 1, there is a tenfold increase in the number of hydrogen ions. Small changes in pH can create huge problems within the body.

PaCO2
This is the partial pressure of carbon dioxide dissolved within the arterial blood. It is used to assess the effectiveness of ventilation. The normal range for a healthy person is 4–6kPa, although in chronic pulmonary diseases it may be considerably higher and still normal for that patient.

PaO2
This is the partial pressure of oxygen dissolved within the arterial blood and will determine oxygen binding to hemoglobin (SaO2). It is of vital importance but is not used in determining patients' acid base status.

The normal range for a healthy person is approximately 10 less than the percentage of oxygen breathed in. For example, we breathe in air, which at sea level contains 21% oxygen, thus the expected SaO2 should be at least 11kPa.

Levels that are higher than normal are usually associated with unnecessarily high levels of supplementary oxygen, while low readings indicate hypoxemia (Simpson, 2004).

SaO2
The arterial saturation depends on the PaO2 but also the hemoglobin (Hb). Although similar to SpO2 (measured by a pulse oximeter), it is more accurate. The normal levels are 97% and above, although levels above 90% are often acceptable in critically ill patients.

HCO3 or SBC

HCO3 is the chemical formula for bicarbonate, an alkali. It is the main chemical buffer in plasma and alludes to the body's metabolic status. It is not directly measured but calculated from other values such as the PaCO2, hemoglobin (Hb) and pH using complicated formulas. Some analyzers use the standard bicarbonate measurement (SBC). Again this is not measured but is calculated and slightly more accurate than HCO3 as it takes into account bicarbonate produced as a result of respiratory failure (Simpson, 2004).

Several textbooks publish many different normal ranges for HCO3. It is easy to remember the normal range as being in the 20s (mmol/l). If the HCO3 is in the low 20s it might be heading out of range, and if it is in the high 20s this also indicates it is heading out of range. The ideal number would be somewhere in the middle, such as 24, 25 or 26mmol/l.

Base excess (BE)

For many practitioners this is perhaps the most confusing element of the ABG report. Base excess is a surplus amount of base (alkali) within the blood. However, it can be normal to have a small amount of surplus within the blood. When there is no surplus base within the blood, rather confusingly it is reported as a negative base excess. However, this too can be normal. The normal range can be anywhere on the linear scale between –2mmol and +2mmol per liter of blood.

The concept of negative base excess can be explained as follows – imagine there is a conical flask within the body and it stores 'base' in case the body might need it. If, for example, the pH falls and the blood becomes acidic, the body will draw on this base, pulling it out of storage and using it to 'mop up' the acid. The body now has none in storage, that is, a negative base excess exists.

If the base excess were reported as +1mmol, this means that in theory 1mmol of base needs to be removed per liter of blood to return the pH to 7.4. Conversely, a base excess of –1mmol means that the blood would have a pH of 7.4 if an extra 1mmol of base were added to each liter of blood.

Nurses who find it difficult to understand the concept of double negatives may prefer to use the normal bicarbonate range when analyzing ABGs and refer to the BE as a quality control measure. This is because HCO3 and BE work in harmony – they are effectively measuring the same thing. If the HCO3 is out of range and reading high, the BE will also be out of range and reading high (in this case a positive number, greater than 2). If the HC03 is out of range and reading low, the BE will also be out of range and reading low (in this case a negative number, less than –2).

Other parameters

The more sophisticated blood gas analyzers are also able to measure lactate, glucose, crude urea and electrolyte levels, Hb and the anion gap. Lactate measurement is a particularly important marker in conditions such as sepsis (Dellinger et al, 2008).

While the focus of this article is on basic arterial blood gas analysis, once they are proficient in this, nurses may study further concepts.

The second part of this unit, to be published next week, outlines the various compensatory mechanisms the body uses.

Key references

Dellinger, R.P. et al (2008) Surviving Sepsis Campaign: International guidelines for management of severe sepsis and septic shock. *Critical Care Medicine*; 36: 1, 296–327.

NICE (2007) *Acutely Ill Patients in Hospital: Recognition of and Response to Acute Illness in Adults in Hospital*. www.nice.org.uk

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Simpson, H. (2004) Interpretation of arterial blood gases: a clinical guide for nurses. *British Journal of Nursing*; 13: 9, 522–527.

Woodrow, P. (2004) Arterial blood gas analysis. *Nursing Standard*; 18: 21, 45–52.

First line of defense

When the body suffers pH balance disturbances (whatever the cause), various mechanisms are set in motion to try to regain normality and ultimately preserve life. Metabolic control is the first line of defense and involves an extremely complex buffering system. Buffers are actually weak acids or weak bases, and can be imagined as being like sponges. They can bring about pH changes by either 'soaking up' excess hydrogen ions or 'wringing themselves out' to release hydrogen ions until the problem can be rectified. Buffers are only temporary holding measures and their actions cannot be sustained indefinitely. The buffers in the body include phosphate, the carbonic acid-bicarbonate system and plasma proteins such as albumin.

Carbonic acid-bicarbonate system
The equation $CO2 + H2O \leftrightarrow H2CO3 \leftrightarrow H+ + HCO3$ is fundamental to understanding acid base balance. Central to the equation is carbonic acid, a weak acid that can split to the 'left' to form carbon dioxide and water, or to the 'right' to form hydrogen and bicarbonate.

When carbonic acid splits to form carbon dioxide and water, it can be excreted via the lungs and the kidneys respectively. When it splits to the right it forms hydrogen and bicarbonate.

Bicarbonate can be excreted through the kidneys and can be lowered when used to 'soak up' excess acid in the blood.

Hydrogen is only excreted through the urine in exchange for retention of other ions, mainly sodium. Nurses can check the extent of hydrogen excretion, as 'normal blood' with a pH of 7.4 produces urine with a pH of 5.0.

Second line of defense

When the buffers' capabilities are exceeded, the second line of defense comes into action, which can be recognized within 2–3 minutes of a problem occurring. The chemoreceptors in the body sense the build-up of acids, and messages are sent via the respiratory centre to the lungs to increase the volume and rate of respiration.

Acids can be converted to CO2 by the carbonic acid-bicarbonate buffering system, and then expires from the body. Conversely, if the chemoreceptors sense a reduced amount of hydrogen ions in the blood, the respiratory centre will send messages to the lungs to slow down the respiratory rate and reduce the volume of expiration in an attempt to retain acid. When using early-warning scores to assess patients who are at risk of becoming critically ill, the altered respiratory rate is often noticed first. A PaCO2 level below 4kPa causes alkalosis while a level greater than 6kPa causes acidosis.

Third line of defense

The last is the renal control mechanism of defense. It may be the slowest to initiate but is the most powerful. It often takes hours or even days before any compensation is evident. However, in the very young (when kidneys are immature) and older people (when kidneys may be impaired), this defense mechanism may be diminished or absent. The kidney tubules can influence the blood's pH by selectively reabsorbing and eliminating chemicals.

The kidneys alter the pH of the blood in several ways, which includes their ability to:

- Retain bicarbonate and phosphate, in favour of hydrogen and chloride. This occurs when the body is acidiotic;
- Retain hydrogen and chloride in favour of bicarbonate and phosphate. This occurs when the body is alkalotic;
- Generate more bicarbonate and phosphate.

Compensation

As far as possible, the body will compensate for pH imbalances until all reserve is lost and it can no longer do so.

The older patients are, the more co-morbidities they may be likely to have, thus making compensation more difficult. Similarly, the more serious their condition, the less likely it is that they will be able to compensate.

Compensation involves trying to create a state of 'opposites'. For example, a patient suffering from respiratory acidosis will try to create the opposite state of metabolic alkalosis in order to compensate. Similarly, a patient in respiratory alkalosis will try to move to a state of metabolic acidosis. The principle of compensation is easy to remember as follows – the opposite of respiratory is metabolic and the opposite of acidosis is alkalosis.

Determining the problem
When compensatory mechanisms occur it can be confusing at first to ascertain which abnormal parameter is the primary problem or underlying condition, and which constitutes compensation.

Nurses can make use of the 'golden rules' (discussed in the Portfolio Pages for this unit) and ascertain which parameter is moving in accordance with the pH. If the PaCO2 is moving in the opposite direction from the pH, the patient will have a respiratory disorder. If the HCO3 is moving in the same direction as the pH, the patient will have a metabolic disorder. This should then make the compensatory mechanisms more evident.

Compensation will involve the three main lines of defense discussed above, and it is only a temporary holding measure until the problem can be rectified. Metabolic conditions will be primarily compensated for by the respiratory system and respiratory conditions will rely on the renal system for compensation.

Chemical buffering
Chemical buffering also plays an important role and compensation can be partial or complete (although very rare), bringing the pH into the normal range. This can be confusing for inexperienced practitioners, who might see the pH between 7.35 and 7.45 and think that the patient is well. For this reason it is imperative to take 7.4 as the absolute normal and neutral pH. Anything less than this should be treated as acidotic and anything higher than this should be treated as alkalotic.

[sub]Situations that may lead to overcompensation
It is impossible for patients to overcompensate without external influences. However, in critical care it may be evident that, for example, inappropriate ventilator settings can lead to overcompensation or another problem.

Conclusion

ABG interpretation takes practice. The more that nurses use this skill, the more competent they will become. Practitioners should allow a senior colleague to check their interpretation and remember that the result is never considered in isolation from other factors and clinical findings.

Although oxygen is very important, it is not used in the actual diagnosis of the condition. Nurses can always add extra oxygen or reduce it accordingly. It is important that practitioners never remove oxygen to obtain a baseline ABG result on air. It is better to titrate the oxygen according to subsequent ABG results (also refer to the '10 less rule' discussed in part 1 of this unit).

While patients are ill it is imperative that practitioners endeavor to treat the underlying cause, as compensation alone will not provide a cure. It must be recognized as a temporary holding measure. Practitioners should act on their instincts and be aware that there may be more than one failing system.

Arterial blood gases (ABGs) provide information about the patient's respiratory and metabolic status. Nurses need to understand the degree to which blood gases vary between normal limits and how the body compensates for acute and chronic changes. The physiology of the control of blood gases and normal and abnormal values are discussed in detail in parts one and two of this series.

The following case studies illustrate how blood gas analysis can assist in the diagnosis of disease.

Acute respiratory alkalosis
Case study one:
Paul, who is 18, has just undergone bowel surgery. On admission to the HDU he is very anxious, short of breath, and complaining of extreme pain, palpitations and dizziness. The heart monitor shows that he is tachycardic, slightly hypertensive and his oxygen saturations are 96%. Blood gases are taken in order to evaluate his condition:

- pH: 7.48;
- PO_2: 12kPa;
- PCO_2: 3.1kPa;
- HCO_3: 24mmol/l;
- BE: +2;
- Changes: increased pH (greater than 7.45), low PCO_2 (less than 4.5kPa), bicarbonate normal.

Interpretation Any conditions that cause hyperventilation can result in respiratory alkalosis, which is characterized by excessive elimination of carbon dioxide from the blood that causes the blood's pH to rise. As this is an acute respiratory event the bicarbonate levels will remain normal. Nervous system alterations might include light-headedness, blurred vision, confusion, sweating and dry mouth.

Cardiovascular symptoms such as palpitations and arrhythmias might also be experienced. The patient may also complain of tetanic spasms (muscle rigidity and spasms) in the arms and legs.

Treatment will centre on resolving the underlying problem. Hypoxia may be a contributory factor and oxygen therapy may be required. Paul may be hyperventilating because of his pain and require analgesia. If the symptoms are associated with a panic attack the cause should be identified and resolved if possible, and the patient should be reassured. For example, Paul might benefit from the presence of his friends or family.

Hyperventilation may result in severe fatigue and the patient should be encouraged to rest. The patient might be encouraged to rebreathe his own carbon dioxide by breathing into a paper bag or cupped hands. If the patient is on a mechanical ventilator the rate and/or volume settings may require adjustment.

Pyrexia and sepsis may result in an increased metabolic rate and antipyretics and antibiotic therapy may be required.

Acute respiratory acidosis
Case study two
Joan has been admitted with a severe chest infection. She is short of breath, agitated and disorientated. Initial observations reveal that she has pyrexia, is tachycardic (pulse rate above 100) and her oxygen saturation levels are 88%. Her ABGs are as follows:

- pH: 7.31;
- PO_2: 8kpa;
- PCO_2: 7kPa;
- HCO_3: 25 mmol/l;
- BE: -2;
- Changes: pH reduced (less than 7.35), PCO_2 raised (greater than 6kPa), bicarbonate normal.

Interpretation Respiratory acidosis is characterized by alveolar hypoventilation that results in an accumulation of carbon dioxide in the blood that combines with water to form carbonic acid, lowering the pH of the blood. Any condition that causes alveolar hypoventilation may cause respiratory acidosis. In the short term there is insufficient time for renal compensation by reabsorption of bicarbonate so the bicarbonate concentration remains almost unchanged.
Signs and symptoms of respiratory acidosis may include dyspnea, shallow respirations and/or respiratory distress, tremors, headache, restlessness and confusion. The patient may also become tachycardic or develop cardiac arrhythmias.

Initial management is to maintain a patent airway, increase ventilation and monitor the patient's vital signs and neurological status closely. Respiratory acidosis can lead to shock and cardiorespiratory arrest if untreated. Joan should be encouraged and assisted to breathe deeply, cough and might be given chest physiotherapy and prescribed supplemental oxygen.

It is important to remember that oxygen alone will not solve the problem. Any underlying conditions will require treatment, for example, suction to remove secretions, analgesia to promote adequate chest expansion (particularly indicated following surgery or trauma) or antibiotics to manage a chest infection. Narcotic antagonists might be prescribed to reverse the effects of opiate overdose or sensitivity.

Bronchodilators may be prescribed, or respiratory support might be initiated to decrease the effort associated with breathing, for example non-invasive ventilation. The hypoxic patient (such as Joan) may also become too confused and agitated to tolerate oxygen therapy. Sedatives might be prescribed but this adds to the risk of further depressing the patient's respiratory status.
If Joan's safety cannot be maintained she may need full sedation and mechanical ventilation until the underlying condition is resolved.
Acute metabolic acidosis

Case study three
Terry has type 1 diabetes controlled on insulin. He has just been admitted into A&E with increased drowsiness. His mucous membranes are dry, and his skin is warm to touch. He breathes rapidly and deeply, and his breath has a distinctive 'fruity' odor. His ABG results are as follows:

- pH: 7.31;
- PO_2: 14kPa;
- PCO_2: 4.2kPa;
- HCO_3: 19mmol/l;
- BE: -4;
- Changes: decreased pH (less than 7.35), decreased bicarbonate (less than 22mmol/l), PCO_2 normal or slightly reduced.

Interpretation This condition is caused by a metabolic problem leading to either a deficit of an alkali in the bloodstream or an excess of acids other than carbon dioxide (Morton et al, 2005). The bicarbonate is lower either because it is used as a buffer or because it has been eliminated. The PCO_2 might be reduced as the lungs try to compensate by breathing out more carbon dioxide thus reducing serum levels of carbonic acid. This results in an increase in the respiratory rate.

The patient might complain of a headache or become confused, restless or lethargic and this may progress to a coma. Cardiac arrhythmias are common and the patient might display 'Kussmaul's respiration' which is characterized by deep and frequent breaths as the lungs try to compensate for the pH by blowing off CO_2. Nausea and vomiting, and warm flushed skin may also be observed.

Treatment of metabolic acidosis depends on the underlying cause, for example insulin therapy is used to treat a patient with diabetic ketoacidosis. If the patient is having diarrhea this will require treatment and the patient will need to be rehydrated. The patient might require dialysis if renal failure is the identified cause. Administration of sodium bicarbonate to treat metabolic acidosis is controversial and should be given with extreme caution.

Hypoxic tissue beds can produce metabolic acids as a result of anaerobic metabolism even if the PO_2 is normal, for example lactic acidosis (excess lactic acid) following cardiac arrest. Therefore it is very important that the patient is assessed for hypoxic tissue in the body when metabolic acidosis occurs.

The following are Q/As from a discussion of the latest trends in blood gas analyzers with **Alan Beder**, Manager of Scientific Affairs, Radiometer America Inc, Westlake, Ohio; **Howard Deahr**, Vice President of Worldwide Marketing for Nova Biomedical Corp, Waltham, Mass; and **Britteny Garner**, product manager for OPTI Medical Systems Inc, Roswell, Ga.

Q: **As computer chips and algorithms have improved over the last 5 years, in general, what features and advantages do today's blood gas analyzers have over previous generations?**

Garner: Improvements in computer technology have led to some exciting improvements in blood gas analyzers in recent years. Blood gas analyzers are smaller and faster than ever with more powerful data-management capabilities. Advancements in algorithms have led to greater accuracy, smaller sample sizes, and faster measurement times. Our OPTI R analyzer returns measurement results in less than 1 minute. When you add it up, all of these improvements have revolutionized point of care testing.

Deahr: Nova blood gas analyzers have taken advantage of computer chips, algorithms, and advanced biosensor technology in several ways. Computerization has been used to automate many tasks that have been performed manually in the past. For example, computerized automation of quality control has eliminated one of the most time-consuming tasks of operating blood gas analyzers—performing and documenting daily quality control. Computerized self-calibrating, self-monitoring, and even self-correction of each analysis and calibration have led to simple, one-button, walk-away automation.

Computerization has also allowed Nova to incorporate additional functions into our blood gas analyzer—such as comprehensive data management and automated maintenance functions. Computer automation, algorithms, and advanced biosensor technology are combined to integrate more tests (as many as 20) into a single, compact analyzer and to reduce analysis time, sample volume, and operating cost.

Q: **As blood-gas analyzers are becoming more sophisticated, are they also becoming more complicated to use—especially for RTs performing point-of-care testing—or has ease-of-use also improved with the technology?**

Garner: Ease-of-use has definitely improved with technology. In fact, much of what makes newer analyzers more sophisticated are the improvements to ease-of-use over older analyzers. I've noticed strong trends toward simpler user interfaces, customizable software, and reduced maintenance on blood gas analyzers. For instance, fourth generation OPTI blood gas analyzers have a touch screen interface that displays easy to follow picture-based instructions that actually reduce training time. Our OPTI CCA-TS requires no daily maintenance, has no standby costs, and has an average time to first service of about 10 years.

Beder: The technological sophistication of the analyzer has actually made ease-of-use improvements possible. Advanced technology has produced simplified user interfaces, automatic quality control, and automated data entry capabilities, to name a few. So, the net effect of technology on ease-of-use has been positive.

Deahr: By automating manual functions like quality control, calibration, and maintenance, Nova blood gas analyzers are easier to use, faster, and more reliable for RTs than ever before. Increased sophistication of these analyzers saves both time and labor, and allows respiratory therapists to spend more time with their patients.

Q: **Tell us about your company's most recent products and why they are innovative for the needs of RTs.**

Garner: OPTI Medical's new OPTI R compact bench-top blood gas analyzer uses our optical fluorescence technology in a reusable sensor cassette that directly measures blood gas, electrolytes, total hemoglobin, and oxygen saturation. The OPTI R has reuseable optical sensors rather than expensive electrodes that require maintenance. The OPTI R comes with a fluid pack with three levels of integrated controls and waste containment. Our software enables users to program the controls to run automatically, which saves lots of time and extra work. Plus the OPTI R is always calibrated so they can put their samples in right away and have the results in 60 seconds.

Beder: Over the past several years, Radiometer has focused on integrating our instruments, samplers, and information technology in a way that reduces the steps in the analytical process, improves patient and operator safety, and minimizes errors.

Deahr: Nova's most recent product introduction is our Stat Profile Critical Care Xpress (CCX) analyzer that offers up to 20 measured tests, including blood gases, chemistry, electrolytes, hematocrit and hemoglobin, and co-oximetry in a single, compact instrument.

CCX expands the role of respiratory therapists as part of the patient care team. Therapists are now able to provide point of care blood gases plus essential electrolytes, chemistry, and hematology results from a single blood sample, with one-button operation, in less than 2 minutes.

Q: **What are the most important things RTs should be aware of when collecting samples for today's machines?**

Beder: As much as 60% of all errors in blood gas testing occur in the preanalytical phase, that is, the phase involved with sample collection and preparation. Preanalytical errors, including improper sample draw and mixing, incorrect sample identification, and the presence of air bubbles and clots in the sample, can all lead to an incorrect result.

Garner: Today's machines are less sensitive to sample handling. The OPTI family of analyzers has heated measurement chambers so iced samples are not a problem. Because of our automated aspiration and bubble detection, sample introduction is not user technique dependent. Our optical fluorescence technology has also reduced the effects of common interfering substances on test results.

Deahr: Along with expanded test menus, today's blood gas analyzers are able to accommodate sample sizes as small as 50 mL. With these smaller sample sizes, it becomes more important that samples are heparinized and mixed properly. Sample mixing is important to assure homogeneity of the sample. For samples from arterial lines, the line must be cleared properly to prevent sample dilution or contamination.

Q: **Are there any precautions RTs should take in order to get the best results?**

Deahr: Proper sample collection, handling, and mixing are important with any blood gas analyzer. For example, glucose results can be affected if the sample is not analyzed within 15 minutes; hematocrit results can be affected if the sample is not mixed properly; blood gases can be affected if air is not expelled from the syringe. Several references are available regarding proper sample handling for blood gases, including *Blood Gases and Electrolytes* by John Toffaletti, PhD, AACC Press.

Q: **What about future trends/products in blood gas analysis that will be coming out in the next generation, or even in the next 5 years? How are they going to be improved over the current generation?**

Garner: With the ever-rising cost of health care, there is great emphasis to reduce costs, especially cost per sample and labor costs. For instance, analyzers will be available with larger test panels, which will reduce the number of analyzers hospitals need to maintain. OPTI Medical is currently working on expanding our test panel. Quality compliance is also a common concern, and I think we will see more analyzers with sophisticated automatic quality monitoring in the future. Data management and wireless connectivity will be of increasing importance in choosing a blood gas analyzer in the next few years as well.

Deahr: Among the future trends in blood gas analysis are expanded test menus, further automation, and reduced labor requirements. Over the long term, we foresee the advent of continuous and less invasive technology.

Beder: In some ways, the future is already here. We see an expansion of the trends already under way, with improvements in IT integration and automation capabilities. In the future, standardized interfaces will enable a more seamless connection between analyzers and the HIS/LIS.

Automated sample handling at the point of care will serve to reduce preanalytical errors at the bedside. And the trend toward including additional parameters with blood gas will continue, resulting in a complete acute care profile in a single instrument.

POCT for arterial blood gases

In 2007, the National Academy of Clinical Biochemistry (NACB) released the final version of the practice guideline "Evidence-based Practice for Point-of-Care Testing."[1]

Similar to other practice guidelines, the NACB POCT guidelines examine each testing area or analyte for evidence of clinical effectiveness. The strength of evidence for improved patient outcome when POCT is used was graded from A to C.

The document cautions readers that use of POCT alone is unlikely to lead to improved patient outcomes without changes in the process of patient care that accommodate more rapid test turnaround times. Readers must decide whether improved patient outcome observed in published studies might be possible to incorporate into their particular practice.

One chapter of the guideline dedicated to critical care testing may be of most immediate relevance. It evaluated evidence for POCT for the following analytes: arterial blood gases, glucose, lactate, magnesium, co-oximetry, electrolytes, and ionized calcium.

The clinical benefit of POCT of ABGs was evaluated in three different settings: the intensive care unit, emergency department, and cardiac surgery.

The authors found fair evidence (grade "B") for use of POCT of ABGs in the ICU. The most convincing evidence for improved outcome occurred when POC blood gas analysis was used with POC lactate as part of a goal-directed therapy for the early detection and treatment of sepsis and shock.[1]

The effectiveness of this approach was demonstrated in a randomized trial of patients presenting to an urban emergency department and admitted to the ICU with either sepsis or shock. Mortality was reduced for patients put on a protocol using POCT methods to monitor blood gas and lactate compared to patients with conventional treatment.[2]

The NACB guidelines go on to describe how in some facilities POC blood gas analysis may offer little time savings compared to central lab analysis of ABG; thus each institution must evaluate the potential benefits of POC blood gas analysis based on its current situation. The document could reach no consensus on whether POC ABG testing reduced costs when compared to central laboratory testing; but indicated that randomized studies are necessary to address this important issue.[1]

Regarding ABG testing by POC in other patient care areas such as ED and cardiac surgery, the guidelines also concluded that evidence was fair (grade "B") for use of POCT. The best evidence for improved patient outcomes with POC blood gas use in the ED was related to the early recognition of shock or metabolic acidosis using pCO_2at the bedside, though lactate may be as or more valuable for this purpose.

Attention on other analytes.

Magnesium testing for critically ill patients has received more attention in the last few years, though the NACB guideline noted that there was still insufficient evidence to determine whether POC magnesium results lead to improved clinical outcomes in the critical care setting. Co-oximetry, electrolytes (Na, K, CL-), and ionized calcium were determined to have mostly fair (grade "B") evidence of improved outcome with the use of POC in most critical care settings.[1]

Glucose

Glucose POCT received a grade of "A," indicating that use of POCT was associated with improved patient outcomes. For glucose, it was noted that use of POCT to control hyperglycemia in conjunction with tight glycemic control protocols improves outcomes for many patients. Rapid detection of hypoglycemia in patients on insulin therapy also reduces harm.

Glucose testing by POC was strongly endorsed by the authors because there was both demonstrated benefit to more rapid turnaround time of results, and demonstrated evidence that use of POCT reduced turnaround time relative to central lab testing and improved patient outcome.[1]

Lactate

Lactate was the other critical care analyte to receive an "A" recommendation based upon evidence that improved turnaround time for lactate testing improved patient outcomes. The strongest evidence came out of studies examining the rapid detection and treatment of sepsis and shock.[1]Recognition and treatment of sepsis is becoming a priority for many health care organizations, and it has become a quality indicator for some health care groups. Evidence that rapid turnaround time for lactate testing may lead to improved patient outcomes is of great importance.

A recent study used POC lactate measurement for goal-directed therapy to keep lactate levels below set thresholds and found better patient outcomes compared to historical controls that did not use POC lactate or goal-directed therapy.[3]

Another study compared two central laboratory (plasma-based) lactate assays to three whole blood lactate assays and found that most whole blood lactate assays agree well with the laboratory reference method up to 6 mmol/L.[4]

Because many laboratories struggle with rapid turnaround time for lactate measurement, and because many institutions are beginning to focus on sepsis outcomes, demand for POC lactate measurement is likely to increase in the future.

Creatinine

Although the NACB guidelines found that evidence for improved outcomes in critical care settings was not good for POC creatinine (grade "C"), the authors of this section also note that evidence is fair (grade "B") for use of POC creatinine to speed therapeutic decisions in procedural areas where creatinine must be known to dose contrast agents or other drugs.

Many institutions now are focusing on reducing temporary or permanent kidney damage caused by contrast agents in patients at risk for renal damage; therefore, rapid turnaround time for creatinine measurement is desired in many outpatients' procedural areas.

Consolidation of testing platforms

Consolidation of testing platforms has been driven by two factors: increasing evidence for improved patient care outcomes for analytes such as glucose, lactate, and creatinine; and the desire to use a single platform in multiple patient care settings.

In general, platform consolidation for respiratory and critical care has taken either a "top down" or "bottom up" approach.

The top-down approach refers to manufacturers that have converted central laboratory blood gas analyzers into POC critical care devices, generally using multiple-use test cartridges to replace fixed reagents and tanks.

The bottom-up approach refers to manufacturers of single-use POC devices attempting to develop more analytes or cartridges for handheld platforms.

Multiple vendors have introduced top-down multiple-use cartridge devices that consolidate blood gas, co-oximetry, and critical care analytes on a single platform. As a class of devices these offer blood gas with co-oximetry, a broader test menu including optically measured hemoglobin, and often glucose, lactate, and creatinine. For neonatal testing some also offer a total bilirubin measurement.

In addition to breadth of menu, other advantages to these devices include on-board quality control and various forms of automated function checks and QC tracking to simplify regulatory compliance and potentially improve the quality of testing. The disadvantage to these devices is that they are not handheld or as easily moved between locations as single-use handheld devices, and operation may require more oversight and training compared to handheld device use.

Examples of the bottom-up approach of adding more analytes to single-use handheld devices include devices that combine basic blood gas analysis with a subset of critical care analytes, most often creatinine and lactate, or alternatively offer co-oximetry using a handheld device. Those devices that do not perform co-oximetry (most in this class) rely on a conductivity-based hematocrit measurement rather than an optical hemoglobin measurement.

This distinction is important mainly for only one patient population - when hematocrit or hemoglobin measurement is desired during cardiopulmonary bypass procedures.

Conductivity-based measurement of hematocrit may produce clinically unacceptable results in patients with low hematocrit who have received fluid used to prime cardiac bypass circuits. This was observed in one study and is most likely a limitation of all devices that use conductivity to measure hematocrit.[5]

Some manufacturers of single-use devices that measure hematocrit by conductivity have attempted to address this issue by providing two different on-instrument calculations for hematocrit. One is used for patients on cardiac bypass, and the other test is used for all other patients. Use of an optically measured hemoglobin probably is a better option for measuring hemoglobin or hematocrit during bypass.

Waived testing update

The final trend that deserves attention is the movement towards a greater variety of platforms that are approved as waived devices by the Food and Drug Administration. The FDA classifies tests as waived or non-waived (moderate or high complexity).

A waived test is one which is simple to perform such that the average lay person could perform it without difficulty. The testing requires no sample processing or reagent preparation, is automated and does not require operator intervention, or does not require test interpretation.

Waived testing has advantages in many settings in that requirements for initial and ongoing analytical validation are reduced for waived testing.

In addition, laboratories that perform only waived testing have reduced requirements for testing and laboratory director personnel training and competency, and they largely avoid the requirement for laboratory inspections and proficiency testing. However, until recently, there were very few general chemistry or electrolyte tests offered as waived, and platforms to perform multiple waived chemistry tests were limited.

The FDA's approval of a single waived platform that offers a wide variety of electrolyte and general chemistry testing created much excitement in the POC community.

This device offers a basic metabolic panel (Na, K, CL-, Ca, creatinine, glucose, BUN, tCO_2 along with lipid testing and additional tests of hepatic function on a single waived platform, with most tests requiring around 100 microliters of whole blood. A second device approved by the FDA offers hematocrit (conductivity-based), calculated hemoglobin (from hematocrit), ionized calcium, Na, K, CL-, glucose, and BUN on a single waived cartridge.

The recent FDA approval of two platforms with electrolyte testing raised hopes that the realm of waived analytes might soon expand into blood gas and other critical care areas. However, the FDA recently has released new guidelines to manufacturers on the steps necessary to obtain approval for new waived tests.

The guidelines provide new direction and suggest that obtaining waiver status may become more difficult in the future. For example, waived tests that require some sample processing currently exist, but new guidelines suggest these are not optimal tests for waived status. The guidelines also mandate that manufacturers demonstrate that there is an "insignificant risk of an erroneous result." This requires manufacturers to evaluate all sources of error and risk (of erroneous results) in new applications for waiver.

Thus, some industry experts believe it will be difficult for devices designed to measure analytes such as blood gas in critically ill patients to obtain waived status. Despite the recent availability of platforms deemed CLIA waived with general chemistry and electrolyte capabilities, it remains unclear whether additional tests for measurement in the critical care arena will be waived in the future.

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Historical background

Since the first system was invented in 1957, blood gas analysis has revolutionized clinical medicine and patient care. During the 1960s, blood gas analysis became almost universally available, and blood gases were considered "the most important laboratory test for critically ill patients," according to a www.bloodgas.org article by Dr. John Severinghaus, inventor of the blood gas analysis system.

Blood gas tests determine whether a patient has enough oxygen in his blood and whether that blood is pH balanced. The tests reveal levels of pH (indicating blood's acid/base status), pO_2 (how much oxygen is dissolved in blood), PCO_2 (how much carbon dioxide gas is dissolved in blood), as well as other parameters like O_2 saturation and HCO_3. Blood samples are collected from an artery, usually the radial artery in the wrist, but also can be taken from the brachial or femoral arteries. For infants, capillary blood may be taken from a heelstick. In addition to arterial sampling, blood gas panels can be ordered on blood drawn through a central venous line to estimate cardiac output.

Blood gas analysis is performed by trained health-care providers in a hospital, emergency room, or large clinical laboratory. These tests are "stat" tests, meaning they should be done as quickly as possible after sample collection. For arterial blood gases (ABGs), the collected sample degrades quickly and, if any testing delay is expected, it should be kept on ice and rewarmed later for accurate analysis. If, after sample collection, any air bubbles remain in the top of the syringe, they must be removed. After the needle is capped, the syringe is then placed on ice and transported for immediate analysis.

To reduce transport as well as turnaround time, especially for the most seriously ill patients, many analyzers are located in or near selected patient care settings, such as intensive care units (ICUs), operating rooms (ORs) and emergency departments. Because ABGs are the most common tests ordered in ORs and ICUs, immediate results are critical. Therefore, many health-care providers are choosing blood gas analysis that is performed via point-of-care testing (POCT), using handheld units that give a quick result at the bedside or operating table. Such handheld units can be used in non-traditional settings such as rural clinics and in ambulance or helicopter transport situations.

POCT can offer several benefits, most importantly the instant implementation of treatment decisions rather than waiting, sometimes for several hours, for the results from a more traditional central laboratory-based analyzer. By the time those results become available, the condition of the patient may have changed. In the case of POCT, immediate results mean immediate care. Specimen transport time is minimized as no staff have to leave the OR or bedside to carry a sample to the lab. In some cases, there may even be a reduction in pneumatic tube traffic. POCT also reduces the risk of preanalytical errors that may accompany traditional laboratory testing, such as the handling, labeling, and transport of samples.

Another advantage to POCT is a decrease in phlebotomy-related blood loss, an important feature in settings like the OR or ICU, where blood conservation is key. Some analyzers used in central laboratories have menus that require a minimum sample size, whereas POCT devices use smaller samples.

The reality of POCT, despite all of these benefits, is that the advantages of POCT are lost when a sample is mishandled, or testing is done incorrectly. Therefore, implementation of point-of-care tests inherently demands structure and regulation (per JCAHO and CLIA regulation) to ensure quality results. POCT places a burden on department and site directors to properly identify the training needs of non-laboratorians, and to ensure that they are met. Additionally, non-laboratorian staff trained on POCT methods must be monitored following the trainings in order to insure their competency with the tests. Training a diverse non-laboratorian staff (including MDs, RNs and RTs) across multiple shifts, instruments, methods, and then monitoring their competency over time is a formidable task which increases with each test introduced and with department size. It is easier to decentralize the test itself than it is to decentralize the specialized laboratory knowledge and training that goes with each test.

Lack of adequate documentation may be considered another drawback to POCT. Results from POCT devices usually appear on a screen with temporary printouts available. Those results may get mishandled or misplaced and never find their way into the patient's permanent medical record. This lack of documentation may also have an effect on potential reimbursement issues.

As health-care providers must consider each advantage and disadvantage to POCT, its technology continues to develop. The analyzers are getting faster, smaller, easier to use, and show the ability to perform accurate testing with smaller blood samples. Radiometer America, Westlake, OH, manufactures one such model, called the 1st automatic blood gas analysis system. The system combines instruments, samplers and information technology to reduce the steps in the analytical process, improve patient and operator safety, and minimize errors.

It consists of the safePICO pre-barcoded arterial sampler that helps to remove air bubbles and avoid contact with patient blood while reducing the risk of needlesticks with an onboard safety device; FLEXLINK software to help ensure correct sample, patient, and operator identification; and the FLEXQ module on the ABL800 FLEX analyzer to help reduce errors through automatic identification and mixing of samples.

Abbott Laboratories, Abbott Park, IL, produces the widely used i-STAT 1 handheld system, which gives results in as little as two minutes using as little as two drops of blood along with a test cartridge. The system is capable of performing a comprehensive panel of critical tests and, according to the manufacturer, is simple to learn and operate.

Of course, the decision to use POCT instead of a central laboratory depends on various factors unique to a particular hospital or health-care setting. One thing is for certain, the transfer of blood gas analysis from the laboratory to the ICU and OR will profoundly affect critical care, just as the introduction of laboratory-based blood gas analyzers did more than 40 years ago.

Arterial blood gas values reflect ventilation and acid-base balance. The results include the arterial blood pH (concentration of hydrogen ions in the blood), partial pressure of carbon dioxide (PaCO2) dissolved in the arterial plasma, and the concentration of sodium bicarbonate (HCO3-) in the blood. Our bodies regulate an acid-base balance through a "buffer system." This buffer system neutralizes acids. There are three buffer systems that exist for the maintenance of our acid-base equilibrium: a buffer system in our blood, respiratory system, and renal system.

Some of the common causes of the retention of carbon dioxide (respiratory acidosis) are:
pneumonia, drug overdose, pulmonary edema, pneumothorax

Some of the common causes of the respiratory alkalosis are:
pain, fever, asthma, congestive heart failure (CHF), anxiety, fear, pulmonary embolus

Some of the common causes of a gain of metabolic acids or a loss of base (metabolic acidosis) are:
Increased acids: renal failure, diabetic ketoacidosis, aspirin overdose, anaerobic metabolism
Loss of base: diarrhea

Some of the common causes of gain of base or loss of metabolic acids (metabolic alkalosis) are:
Gain of base: Increased ingestion of antacids or an excessive administration of sodium bicarbonate
Loss of metabolic acids: vomiting, nasogastric suctioning, low potassium and/or chloride levels, diuretics, steroids, increase in aldosterone.

Basic Questions:

There are three critical questions to keep in mind when attempting to interpret arterial blood gases (ABGs).

First Question: Does the patient exhibit acidosis or alkalosis?
Second Question: What is the primary problem? Metabolic? or Respiratory?
Third Question: Is the patient exhibiting a comensatory state?

These essential questions will guide you while you analyze ABGs.

In order to understand ABG analysis and remember what is abnormal, we would be wise to review what is normal.

Normal Values:

Normal Values and Acceptable Ranges of the ABG Elements

ABG Element	Normal Value	Range
pH	7.4	7.35 to 7.45
Pa02	90mmHg	80 to 100 mmHg
Sa02		93 to 100%
PaC02	40mmHg	35 to 45 mmHg
HC03	24mEq/L	22 to 26mEq/L

Remember: Definitions

Acidosis (acidemia) occurs when pH drops below 7.35

Alkalosis (alkalemia) occurs when the pH rises above 7.45

A primary respiratory problem is determined if the PaC02 is less than 35mmHg(alkalosis) or greater than 45 mmHg(acidosis).

A primary metabolic problem is when the HC03 is less than 22mEq/L (acidosis) or greater than 26mEq/L(alkalosis).

Assessment: Assessment Step 1 :: pH

Step One: Determine the acid/base status of the arterial blood. Keep in mind what is Normal

If the blood's pH is less than 7.35 this is an acidosis, and if it is greater than 7.45 this is an alkalosis.

You may hear nurses or doctors say: "The patient is 'acidotic' or 'alkalotic'

Assessment :: Assessment Step 2 :: Respiratory vs. Metabolic

Step Two: Once you have determined the pH, you can move on to determine the 'primary' problem, or which system, respiratory or metabolic is the prime messenger. Let's look at the two systems and understand the rationale behind determination of the 'primary' problem.

Respiratory System

If you keep in mind that carbon dioxide acts as the 'acid' of the human body, you will be able to determine if the primary acid-base imbalance is respiratory. Chemically speaking, there is an equilibrium between carbonic acid and bicarbonate. Therefore, just remember that an increased PaCO2 (greater than 45mmHg) along with an acidosis (pH less than 7.35) represents a RESPIRATORY ACIDOSIS. If you have a situation where there is a decreased PaCO2 (less than 35mmHg) and an alkalosis (pH greater than 7.45) you will have a RESPIRATORY ALKALOSIS! Easy. Right?

Metabolic System

Keep in mind that HCO3 represents a 'base' situation, and if there is an increased HCO3 (greater than 26 mEq/L) in an alkalotic environment (pH greater than 7.45) there is a METABOLIC ALKALOSIS. On the opposite side of the coin, if there is a decreased HCO3 (less than 22 mEq/L) in an acidic environment (pH less than 7.35) this will be representative of METABOLIC ACIDOSIS.

Assessment: Assessment Step 3: Compensation

Step Three: Our bodies have compensatory mechanisms that assist us to return to a state of homeostasis (equilibrium). The body attempts to compensate for whatever the primary problem is in an effort to return the acid-base balance to normal. An illustration of COMPENSATION is given below:

> A newly diagnosed Type 1 diabetic client has a 'primary' problem of metabolic acidosis (pH 7.29; HCO3 16 mEq/L) due to an increase in ketone bodies (ketoacidosis). The nurse notes that the ABGs show a below normal PaCO2 value (27mmHg) and the client is breathing faster in an attempt to 'blow off' the carbon dioxide (CO2:'acid') to create a respiratory alkalosis, the opposite of metabolic acidosis!

Hint! In order to recognize 'compensation' look for a change in the buffering system that was not involved in the 'primary' problem.

Example: If a client is demonstrating signs and symptoms of respiratory acidosis and the ABG results are something like: pH 7.27 and a PaCO2 of 58 mmHg and the body is compensating for this 'primary' abnormality, the other buffer system (primarily HCO3) will be changed (e.g. elevated HCO3: 30mEq/L).

The convenience is that the 'other buffer system' change will be in the 'same direction' as the 'primary problem.' In this example the PaCO2 is elevated and the compensatory system (HCO3) is above the normal range. Consequently, they are both elevated! This tells you that the human body is compensating for the 'primary problem!'

Therefore, you were able to determine that there was an elevated PaCO2 (increase in acid or a respiratory acidosis) and an increased HCO3 (increased base or metabolic alkalosis).

But you were able to determine respiratory acidosis as the 'primary problem' due to the pH being less than 7.35! This example illustrates a respiratory acidosis with a compensatory metabolic alkalosis. The opposite system will come to the rescue!

now it is time to review the three essential steps of ABG analysis!

Number One!

Determine if the client is demonstrating an acidotic (remember: pH less than 7.35) or alkalotic (pH greater than 7.45).

Number Two!

What is the 'primary problem'

If the client is acidotic with a PaC02 greater than 45 mmHg it is RESPIRATORY

If the client is acidotic with a HC03 less than 22 mEq/L it is METABOLIC!

If the client is alkalotic with a PaC02 less than 35 mmHg it is RESPIRATORY!

If the client is alkalotic with a HC03 greater than 26 mEq/L it is METABOLIC!

Number Three!

Is the client compensating?

Are both components (HCO3 and PaCO2) shifting in the same direction? Up or down the continuum? Above or below the normal ranges? If this is noted, you know that the client's buffering systems are functioning and are trying to bring the acid-base balance back to normal.

Case Studies: Case Study 1

A client recovering from surgery in the post-anesthesia care unit (PACU) is difficult to arouse two hours following surgery. The nurse in the PACU has been administering Morphine Sulfate intravenously to the client for complaints of post-surgical pain. The client's respiratory rate is 7 per minute and demonstrates shallow breathing. The patient does not respond to any stimuli! The nurse assesses the ABCs (remember Airway, Breathing, Circulation!) and obtains ABGs STAT!

The STAT results come back from the laboratory and show:

pH = 7.15
Pa C02 = 68 mmHg
HC03 = 22 mEq/L

Once you have interpreted the ABG results, click on one of the following links

- Compensated Respiratory Acidosis
- Uncompensated Metabolic Acidosis
- Compensated Metabolic Alkalosis
- Uncompensated Respiratory Acidosis

After you have made your choice, then look up the definition of your choice to see if it is correct. Correct answers to these case studies will not be given here—is up to you to do research! Click "control" and the link to see if your choice was correct.

Case Studies: Case Study 2

An infant, three weeks old, is admitted to the Emergency Room. The mother reports that the infant has been irritable, difficult to breastfeed and has had diarrhea for the past 4 days. The infant's respiratory rate is elevated and the fontanels are sunken. The Emergency Room physician orders ABGs after assessing the ABCs.

The results from the ABGs come back from the laboratory and show:

pH = 7.37
Pa C02 = 29 mmHg
HC03 = 17 mEq/L

Once you have interpreted the ABG results, click on one of the following links

- Compensated Respiratory Alkalosis
- Uncompensated Metabolic Acidosis
- Compensated Metabolic Acidosis
- Uncompensated Respiratory Acidosis

After you have made your choice, then look up the definition of your choice to see if it is correct. Correct answers to these case studies will not be given here—is up to you to do research! Click "control" and the link to see if your choice was correct.

Case Studies: Case Study 3

A client, 5 days post-abdominal surgery, has a nasogastric tube. The nurse notes that the nasogastric tube (NGT) is draining a large amount (900 cc in 2hours) of coffee ground secretions. The client is not oriented to person, place, or time.

The nurse contacts the attending physician and STAT ABGs are ordered.

The results from the ABGs come back from the laboratory and show:

pH = 7.52
Pa C02 = 35 mmHg
HC03 = 29 mEq/L

Once you have interpreted the ABG results, click on one of the following links

- Compensated Respiratory Alkalosis
- Uncompensated Metabolic Acidosis
- Compensated Metabolic Acidosis
- Uncompensated Metabolic Alkalosis

After you have made your choice, then look up the definition of your choice to see if it is correct. Correct answers to these case studies will not be given here—is up to you to do research! Click "control" and the link to see if your choice was correct.

Case Studies: Case Study 4

A client is admitted to the hospital and is being prepared for a craniotomy (brain surgery). The client is very anxious and scared of the impending surgery. He begins to hyperventilate and becomes very dizzy. The client looses consciousness and the STAT ABGs reveal:

The results from the ABGs come back from the laboratory and show:

pH = 7.57
Pa C02 = 26 mmHg
HC03 = 24 mEq/L

Once you have interpreted the ABG results, click on one of the following links

- Compensated Metabolic Acidosis
- Uncompensated Metabolic Acidosis
- Uncompensated Respiratory Alkalosis
- Uncompensated Respiratory Acidosis

After you have made your choice, then look up the definition of your choice to see if it is correct. Correct answers to these case studies will not be given here—is up to you to do research! Click "control" and the link to see if your choice was correct.

Case Studies: Case Study 5

A two-year-old is admitted to the hospital with a diagnosis of asthma and respiratory distress syndrome. The father of the infant reports to the nurse that he has observed slight tremors and behavioral changes in his child over the past three days. The attending physician orders routine ABGs following an assessment of the ABCs. The ABG results are:

The results from the ABGs come back from the laboratory and show:

pH = 7.36
Pa C02 = 69 mmHg
HC03 = 36 mEq/L

Once you have interpreted the ABG results, click on one of the following links

- Compensated Respiratory Alkalosis
- Uncompensated Metabolic Acidosis
- Compensated Respiratory Acidosis
- Uncompensated Respiratory Alkalosis

After you have made your choice, then look up the definition of your choice to see if it is correct. Correct answers to these case studies will not be given here—is up to you to do research! Click "control" and the link to see if your choice was correct.

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Glossary of Terms

ABG: arterial blood gas. A test that analyzes arterial blood for oxygen, carbon dioxide and bicarbonate content in addition to blood pH. Used to test the effectiveness of ventilation.

Acidosis: a pathologic state characterized by an increase in the concentration of hydrogen ions in the arterial blood above the normal level. May be caused by an accumulation of carbon dioxide or acidic products of metabolism or a by a decrease in the concentration of alkaline compounds.

Alkalosis: a state characterized by a decrease in the hydrogen ion concentration of arterial blood below normal level. The condition may be caused by an increase in the concentration of alkaline compounds, or by decrease in the concentration of acidic compounds or carbon dioxide.

Chronic obstruction pulmonary disease (COPD): a disease process involving chronic inflammation of the airways, including chronic bronchitis (disease in the large airways) and emphysema (disease located in smaller airways and alveolar regions). The obstruction is generally permanent and progressive over time.

Diamox ™: a carbonic anhydrase inhibitor that decreases H^+ ion secretion and increases HCO_3 excretions by the kidneys, causing a diuretic effect.

Hyperventilation: a state in which there is an increased amount of air entering the pulmonary alveoli (increased alveolar ventilation), resulting in reduction of carbon dioxide tension and eventually leading to alkalosis.

Hypoventilation: a state in which there is a reduced amount of air entering the pulmonary alveoli.

Hypoxemia: below-normal oxygen content in arterial blood due to deficient oxygenation of the blood and resulting in hypoxia.

Hypoxia: reduction of oxygen supply to tissue below physiological levels despite adequate perfusion of the tissue by blood.

Iatrogenic: any condition induced in a patient by the effects of medical treatment.

Kussmaul's respirations: abnormal breathing pattern brought on by strenuous exercise or metabolic acidosis, and is characterized by an increased ventilatory rate, very large tidal volume, and no expiratory pause.

Oxygen delivery system: a device used to deliver oxygen concentrations above ambient air to the lungs through the upper airway.

Oxygenation: the process of supplying, treating or mixing with oxygen.

Oxyhemoglobin: hemoglobin in combination with oxygen.

Pneumothorax: an abnormal state characterized by the presence of gas (as air) in the plueral cavity.

Pulmonary Embolism: the lodgment of a blood clot in the lumen of a pulmonary artery, causing a severe dysfunction in respiratory function.

Thyrotoxicosis: toxic condition due to hyperactivity of the thyroid gland. Symptoms include rapid heart rate, tremors, increased metabolic basal metabolism, nervous symptoms and loss of weight.

Advanced Blood Gas Analysis

Select the ***best*** answer to each of the following items. Mark your responses on the Answer form.

1. This course presents a method for calculation of arterial acid-base and blood gas status from measurements in peripheral venous blood combined with a pulse oximeter measurement of arterial _____.

a. blood pressure
b. arterial saturation
c. blood gas volume
d. None of the above

2. The sensitivity of the method has been tested for measurement errors including _____; errors due to physiological assumptions including the values of RQ and strong acid production at the tissues; and errors due to air bubbles in the blood.

a. venous blood acid-base
b. blood gas status
c. pulse oximetry
d. All of the above

3. Blood gas values must always be examined in the light of what it takes to get that patient to that blood gas.

a. True
b. False

4. Every day, practitioners working in acute areas encounter arterial blood gas (ABG) results, which they may not necessarily be able to interpret. It can be difficult to find time to develop knowledge. However, in light of guidance and policy documents (NICE, 2007; Department of Health, 2000), it is imperative that all nurses working in acute areas can interpret ABGs and ensure patients receive timely and _____.

a. appropriate care
b. diagnosis of their condition
c. medication
d. None of the above

5. An ABG is typically requested to determine _____ within it. It is used to assess the effectiveness of gaseous exchange and ventilation, be it spontaneous or mechanical. If the pH becomes deranged, normal cell metabolism is affected.

a. the pH of the blood
b. partial pressures of carbon dioxide
c. partial pressures of oxygen
d. All of the above

6. In order for the ABG sample to be accurate, it should be analyzed within ____minutes of sampling from the patient. To prevent haemolysis it should be handled gently, avoiding any vigorous shaking. Providing constant agitation by rolling the syringe gently will also prevent plasma separation.

a. 10
b. 25
c. 30
d. None of the above

7. For every decrease in the pH by 1, there is a _____ increase in the number of hydrogen ions. Small changes in pH can create huge problems within the body.

a. fivefold
b. tenfold
c. twentyfold
d. None of the above

8. Nurses who find it difficult to understand the concept of double negatives may prefer to use the normal bicarbonate range when analyzing ABGs and refer to the BE as a quality control measure. This is because HCO3 and BE work in harmony – they are effectively measuring the same thing.

a. True
b. False

9. Hydrogen is only excreted through the urine in exchange for retention of other ions, mainly sodium. Nurses can check the extent of hydrogen excretion, as 'normal blood' with a pH of 7.4 produces urine with a pH of _____.

a. 3.0
b. 4.5
c. 5.0
d. None of the above