Smith Seminars
Online Continuing Education
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Arterial Blood Gases

Objectives

- Define arterial blood gas.
- List the indications, contraindications, and proper technique for obtaining arterial blood.
- Identify the normal blood gas values and conditions that will cause abnormal blood gas values.
- Recognize the oxygen dissociation curve.
- List steps to correct blood gas analysis.

Arterial blood gases are obtained by respiratory therapists everyday using methods that have been refined with years of experience. As an important aspect of quality management, respiratory therapists need to be trained and periodically recertified in universal precautions, proper syringe preparation, site determination, puncture technique, sample acquisition, storage and disposal of blood specimens, and care of the puncture site.

Definition

Arterial blood gases or ABGs refers to the measurement of pH, PaCO2, and PO2 in arterial blood.

Measured values for hemoglobin saturations with oxygen (O2Hb), carboxyhemoglobin (COHb), and methemoglobin (metHb) may be included.

Calculated values such as oxygen saturation (SO2), bicarbonate concentration (HCO3), and base excess (BE) may be included.

Indications

Patient's clinical presentation suggests abnormality in oxygenation, ventilation, or acid-base status. Evaluate changes in therapy such as FiO2, applied PEEP, ventilator rate, or tidal volume changes; or acid-base balance such as sodium bicarbonate administration or acetazolamide therapy. ABG's are invasive and costly so they should never be considered routine.

Samples

Blood gas syringes contain dry lyophilized lithium heparin to prevent clotting of the sample. Coagulation of the blood sample must be avoided because clots interfere with the function of blood gas analyzer.

ABG sample must be obtained anaerobically, without contamination of room air. If the sample is contaminated with air, the measured PO2 of the sample increases if the true value is less than 150 mmHg and decreases if the true value is more than 150 mmHg. Contamination of the sample with air lowers the PCO2 and increases the pH.

Arterial blood can be obtained from several arteries, but the radial artery is usually chosen for several reasons:

- Collateral blood flow to the hand via ulnar artery
- Radial artery is far enough away from nerves
- Radial site is more aseptic than femoral site
- Radial artery is usually near the surface and causes less puncture pain

Other arteries that can be used with increased risk of complications are:

- Brachial
- Femoral
- Axillary
- Ulnar
- Dorsalis pedis
- Temporal

Arterial catheter may be indicated if there is a need for continuous monitoring of arterial blood pressure in a hemodynamically unstable patient, or a need for frequent arterial blood gas samples or other laboratory assessment.

Capillary blood gas may be obtained to estimate pH and PCO2, but capillary PO2 measurements are of little value in estimating oxygenation.

Contraindications

An arterial needle stick should never been done in an area with a shunt, fistula, or lesion. The radial artery with a negative modified Allen test should never be used. High levels of anticoagulants are considered to be a contraindication for an arterial needle stick. Patients with a history of a clotting disorder, such as hemophilia or severe peripheral vascular disease is contraindicated.

If the patient is leukemic (leukocytosis > 100,000 cells/ul), samples must be iced and analyzed immediately. Leukocyte larceny is the effect that the PaO2 decreases very rapidly in the sample and the results show a much lower PaO2 than actually exists in the patient.

Difficulties in Obtaining a Sample

If the patient is alkalotic or acidotic, an irritable or constricted vessel is more difficult to puncture. Also hypotension with a weak or absent pulse on palpation will make it more difficult. The patient suffers from a disease such as Parkinsons. The patient is afraid and tense.

Complications

Complications can include embolism, arterial occlusion (prolonged spasm), hematoma, localized infection and/or bacteremia, distal ischemia, thrombosis, or numbness of the hand.

Seven Steps of Obtaining ABGs

1. Evaluate the patient and the orders
2. Choose the site

3. Get comfortable
4. Perform a modified Allen test
5. Use the right tools
6. Prepare the site
7. Handle the sample properly

Evaluate the Patient and the Orders

The RCP should understand the reason for ABG tests. The procedure may be reconsidered if it is not clear that the results will alter the course of treatment. If multiple arterial sticks are anticipated, an arterial catheter should be considered. The patient's oxygen use, breathing pattern, and activity stability should be considered with the ABG results. Explain the procedure and the reason for the procedure to the patient.

Choose the Site

The first choice of puncture sites is the radial artery if there is adequate collateral blood flow assessed by a modified Allen test. The second choice is the brachial artery because it has good collateral circulation, but lies deeper from the surface and is close to veins and nerves. The third choice is the femoral artery, although it poses a risk of infection and needs to be watched for bleeding.

Get Comfortable

The patient should be lying down or sitting in a chair with the arm supported. The respiratory therapist should be sitting if possible, or at least in a comfortable, non-awkward position.

Perform a Modified Allen Test

The respiratory therapist should compress both the radial and ulnar arteries of the patient and ask the patient to make a fist and open their hand until blanching occurs. Then release the compression of the ulnar artery and assess the hand for return of color in 5 to 15 seconds. If the color returns, there is a positive Allen test, and the arterial stick can proceed. If the ulnar filling is poor or no flushing occurs, do not proceed, but try the other wrist for a suitable site.

Use the Right Tools

Capless syringes should be used to draw ABGs if available. If not, then the one hand recapping technique should be used. A vented syringe will allow the therapist to set the volume of blood required for an adequate sample by pulling back on the plunger prior to inserting the needle. Gloves should be worn during the procedure, noting that they protect from blood splashes only and not needle sticks. A folded 2x2 gauze or cotton ball can be used to hold pressure after the arterial stick and a band-aid or tape applied as a pressure dressing for at least 5 minutes. A biohazard bag should be used to transport the blood to the lab.

Prepare the Site

The wrist should be hyper-extended with a rolled towel to allow the pulse to be easily palpated. Clean the skin around the site thoroughly with a 70% isopropyl alcohol wipe, allow it to dry. Locate the artery and insert the needle bevel up, at a 45% angle, advance until you get a blood flash. Once the artery is punctured, stop advancing and allow the arterial pressure to fill the syringe. If the artery is missed, pull the needle back to just below the skin and advance again.

Handle the Sample Properly

Once the blood has been obtained, it is very important that the sample be checked for air bubbles and any removed immediately. Always remove the needle prior to transporting and place a rubber stopper on the syringe. Transport blood gases to the laboratory so analysis can be completed within 30 minutes. As a practical rule, arterial samples do not need to be placed in ice if analyzed within 10 minutes. If the sample must be stored for a long time, more than 30 minutes, a glass rather than plastic syringe should be used.

Blood Gas Values

pH – normal values, 7.35-7.45
Values >7.45 – Alkalosis
Values < 7.35 – Acidosis
Abnormal values of the acid-base values can be metabolic or respiratory. Henderson-Hasselbalch equation describes the relationship between pH, HCO3, and PCO2

$$pH = 6.1 + \log \left(\frac{[HCO_3]}{0.03 \times PCO_2} \right)$$

Changes in pH resulting from changes in HCO3 are called metabolic acid-base disorders. Changes in pH resulting from changes in PCO2 are called respiratory acid-base disorders.

Metabolic alkalosis – increase in pH due to an increase in HCO3.
Respiratory alkalosis – increase in pH due to a decrease in PCO2.
Metabolic acidosis – decrease in pH due to a decrease in HCO3.
Respiratory acidosis – decrease in pH due to an increase in PCO2.

The pH is normal (7.40) whenever the ratio HCO3 to (0.03 x PCO2) is 20:1. A compensated respiratory acid-base disorder occurs when the physiologic change in HCO3 occurs secondary to a PCO2 change so that the HCO3 to (0.03 x PCO2) is 20:1 therefore the pH is normal. Also a physiologic change in PCO2 may occur secondary to a HCO3 disorder so that the HCO3 to (0.03 x PCO2) is 20:1 and a normal pH. (Respiratory compensation for a metabolic disturbance)

Respiratory Acidosis

Uncompensated – pH decreased, HCO3 normal, and PCO2 increased.
Partially compensated – pH decreased, HCO3 increased, and PCO2 increased
Fully compensated – pH normal, HCO3 increased, and PCO2 increased

Respiratory Alkalosis

Uncompensated – pH increased, HCO3 normal, and PCO2 decreased.
Partially compensated – pH increased, HCO3 decreased, and PCO2 decreased.
Fully compensated – pH normal, HCO3 decreased, and PCO2 decreased.

Metabolic Acidosis

Uncompensated – pH decreased, HCO_3 decreased, and PCO_2 normal.
Partially compensated – pH decreased, HCO_3 decreased, and PCO_2 decreased.
Fully compensated – pH normal, HCO_3 decreased, and PCO_2 decreased.

Metabolic Alkalosis

Uncompensated – pH increased, HCO_3 increased, and PCO_2 normal.
Partially compensated – pH increased, HCO_3 increased, and PCO_2 increased.
Fully compensated – pH normal, HCO_3 increased and PCO_2 increased.

Clinical Causes of Common Acid-Base Disturbances

Respiratory acidosis (hypoventilation)
Respiratory center depression: pathologic, iatrogenic
Disruption of neural pathways affecting respiratory muscles: neuropathy, trauma
Neuromuscular blockade: disease, paralyzing agents
Respiratory muscle weakness: fatigue, disease
Respiratory alkalosis (hyperventilation)
Respiratory center stimulation: hypoxia, anxiety, CNS pathology
Iatrogenic: excessive mechanical ventilation
Metabolic acidosis
Lactic acidosis (e.g. hypoxia)
Ketoacidosis (e.g. uncontrolled diabetes)
Uremic acidosis (e.g. renal failure)
Loss of base from lower gastrointestinal tract (e.g. diarrhea)
Loss of base from kidneys (e.g. acetazolamide, renal tubular acidosis)
Poisons (e.g. methanol, ethylene glycol, aspirin)
Metabolic alkalosis
Hypokalemia
Loss of acid from upper gastrointestinal tract (e.g. vomiting or gastric suction)
Bicarbonate administration

The anion gap is useful to differentiate causes of metabolic acidosis.

$$\text{Anion gap} = [Na^+] - ([Cl^-] + [HCO_3])$$

Metabolic acidosis can be associated with a normal anion gap (hyperchloremic acidosis) or with an increased anion gap (normochloremic acidosis). A normal anion gap is 8-12 mmol/l. Causes of metabolic acidosis with a normal anion gap include loss of bicarbonate from the gastrointestinal tract (e.g. diarrhea), acetazolamine therapy, renal tubal acidosis, or excessive chloride administration (e.g. volume expansion with normal saline, HCl, NH_4Cl)

PCO_2

PCO_2 is the partial pressure of dissolved carbon dioxide in blood and is useful in evaluating the respiratory component acid-base status. Normal range for newborns, infants, and children up to 2 years of age, with arterialized capillary blood (heel, fingertip, big toe) or arterial blood is 27-40 mmHg; children older than 2 years of age (arterial) is 27-41 mmHg; adult arterial male is 35-48 mmHg and female is 32-45 mmHg.

Critical values of $PaCO_2$ >45 mmHg may be a risk factor for pulmonary complications. Possible panic range is <20 mmHg and >70mmHg. The term hypercapnia indicates the presence of excessive carbon dioxide in the blood. Disorders associated with hypercapnia include central respiratory depression, abnormal neuromuscular function and chest wall abnormality, upper or lower respiratory track disease, or hypercapnia secondary to cardiac disease.

HCO_3

Bicarbonate makes up about 25 mmol/L of the anions found in normal plasma and is a major contributor to the bicarbonate/carbonic acid plasma-buffering system that maintains acid-base homeostasis. Normal arterial values for children and adults are 21-28 mmol/L. Panic values are <10 mmol/L and >40 mmol/L.

HCO_3 is increased with metabolic alkalosos, respiratory acidosis, and compensated respiratory acidosis. HCO_3 is decreased with metabolic acidosis (e.g. low in ketoacidosis) and compensated respiratory alkalosis. Severe metabolic acidemia bears an implication of bicarbonate levels <8 mmol/L and is treated with intravenous sodium bicarbonate, among other measures.

PaO_2

In a normal healthy individual breathing ambient air, the PaO_2 is about 5-10 mmHg less than the PAO_2. The difference represents the alveolar to arterial (A-a) gradient.

The modified alveolar gas equation can calculate the PAO_2:

$$PAO_2 = (EBP \times FIO_2) - (1.25 \times PaCO_2)$$

EBP (Effective barometric pressure) is the difference between barometric pressure and water vapor pressure at body temperature (47 mmHg at 37 degrees C). An individual breathing room air (FIO_2 = 0.21) at sea level (barometric pressure = 760 mmHg) who has a normal $PaCO_2$ (40 mmHg), the PAO_2 is approximately 100 mmHg. Considering the normal A-a gradient of 5-10 mmHg, the measured PaO_2 would be 90-95 mmHg. The alveolar gas equation predicts that the PAO_2 will be less than 100 mmHg if the barometric pressure is less than 760 mmHg. The normal PaO_2 is lower in higher altitudes and higher in hyperbaric conditions.

PaO_2 also increases with an increase in FIO_2. The alveolar gas equation predicts that the PAO_2 will be about 675mmHg when 100% oxygen is breathed at sea level; the PaO_2 is normally more than 600 mmHg at these conditions.

Hypoxemia

Hypoxemia is defined by a PaO_2 of less than 80 mmHg, in a person breathing room air, at sea level. Hypoxemia refers to decreased delivery of oxygen from the atmosphere to the blood.

Five general causes of hypoxemia:

1. Decreased inspired oxygen, cause of which may be high altitude.

2. Hypoventilation causes of which may include respiratory center depression or neuromuscular disease.
3. Shunt may be caused by atelectasis, pneumonia, pulmonary edema, or ARDS.
4. V/Q mismatch, poor distribution of ventilation, causes of which may be airway secretions or bronchospasm.
5. Diffusion defect may be caused by pulmonary fibrosis, emphysema, or pulmonary resection.

Hypoxia

Hypoxia refers to decreased delivery of oxygen to the tissue. Hypoxemia may occur without hypoxia and vise versa.

Five general causes of hypoxia:
1. Hypoxemic hypoxia may be due to a lower than normal PaO2 (hypoxemia).
2. Anemic hypoxia due to decreased red blood cell count, carboxyhemoglobin, or hemoglobinopathy.
3. Circulatory hypoxia may be caused by decreased cardiac output or decreased local perfusion.
4. Affinity hypoxia due to decreased release of oxygen from hemoglobin to the tissues.
5. Histotoxic hypoxia because of cyanide poisoning.

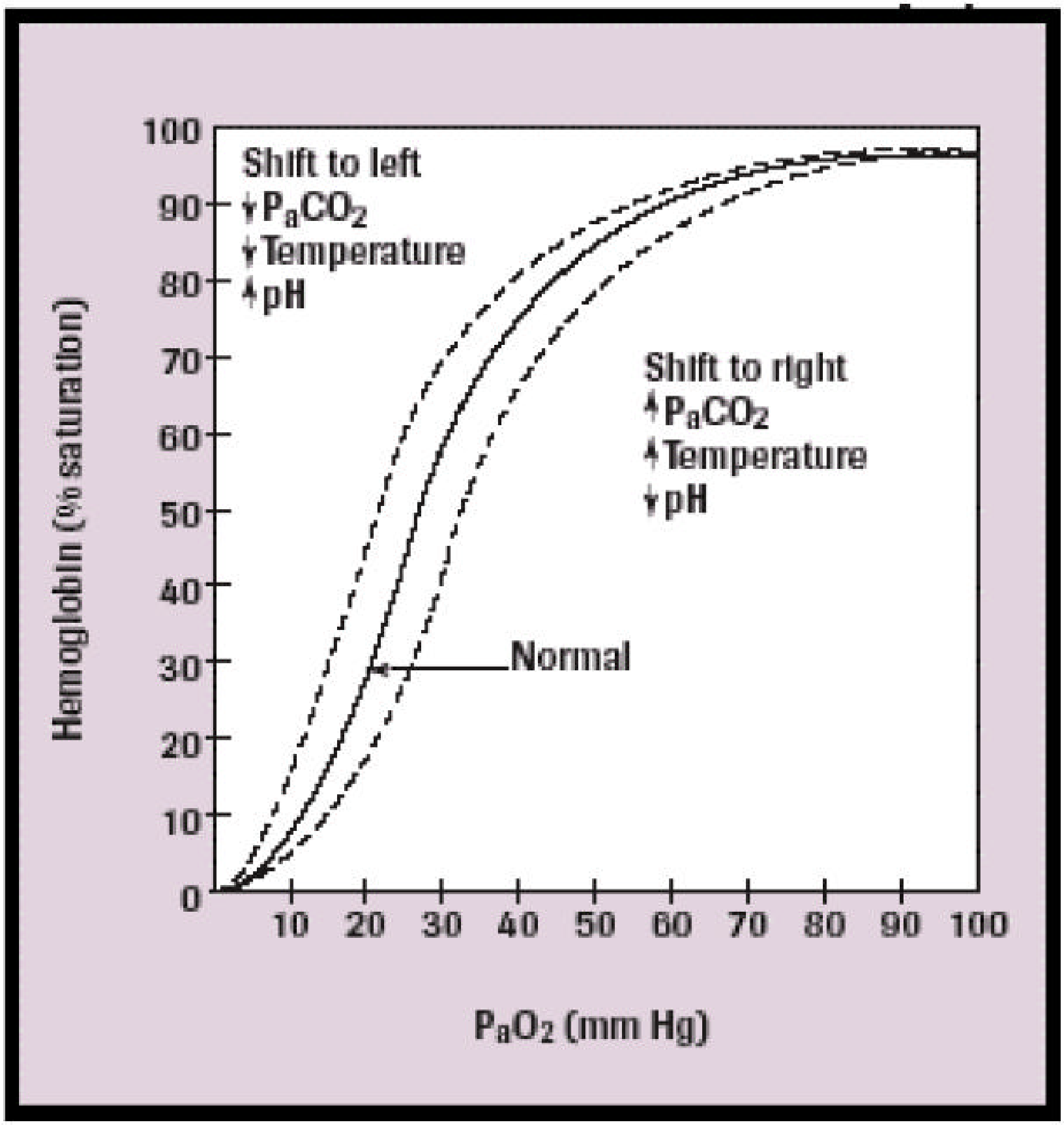
Oxygen Saturation

Oxygen saturation is measured by CO-oximetry. The CO-oximeter measures oxygen saturation by a light absorption method. Multiple wavelength CO-oximetry can measure COHb (i.e. carbon monoxide saturation) and metHb in addition to oxyhemoglobin (i.e., oxygen saturation). Hemoglobin oxygen saturation is the percentage or fractional of functional hemoglobin (i.e. hemoglobin able to bind oxygen) that is oxygenated.

It is determined by the equation:

$$SO2\ (\%) = [CO2Hb / (CO2Hb + CHHb)] \times 100$$

CO2Hb is the concentration of oxyhemoglobin and CHHb is the concentration of deoxyhemoglobin. SO2 (together with pO2, FHbO2, ctO2, FMetHb, and FCOHb) is used to assess the extent of oxygenation of hemoglobin and adequacy of tissue oxygenation in the evaluation of hypoxia due to lung and/or cardiac disease or dysfunction, cyanosis, or toxic exposure. It allows for the evaluation of oxygenation and oxyhemoglobin dissociation of blood with use of the oxygen dissociation curve.



Oxygen Dissociation Curve

If there is a low saturation with a high PaO2, then there is something decreasing the ability of hemoglobin to bind oxygen. A reasonable explanation for this is the presence of COHb or metHb. Pulse oximetry is not appropriate for this evaluation, because it uses only two wavelengths of light and is unable to differentiate oxyhemoglobin, COHb, and metHb. Arterial pO2 of 20mmHg and SO2 of 35% are critically low, life-endangering levels. Arterial pO2 of 40 mmHg and SO2 of 75% are panic values that correlate with cyanosis.

How to Quickly Analyze ABGs

ABGs are used to evaluate the acid-base balance in the body. Balance is crucial to normal functioning of the body's systems. Severe imbalances can be lethal.

4-Step Method of Evaluation

First of all, there are a few key concepts about acid-base evaluation:

pH is an expression of the free hydrogen ion concentration of a substance. Blood has a normal pH of 7.35 to 7.45. An increase in hydrogen ion concentration lowers pH and increases acidity. A decrease in hydrogen ion concentration raises pH and decreases acidity. The body doesn't fully compensate for a primary acid-base disorder; in compensated acidosis the pH will be below 7.40, and in compensated alkalosis it will be above 7.40. The PaCO2 (partial pressure of carbon dioxide) is the respiratory component of the acid-base balance. Normal values range from 35 mmHg to 45 mmHg. The HCO3 (bicarbonate) is the metabolic component of the acid-base balance. Normal values range from 22 to 28 mEq/L.

Step 1

Evaluate the blood pH. Is the pH within normal range of 7.35-7.45? If so, the patient is either normal or compensated. Does the pH tend to acid or alkaline side? Is the patient acidotic with a pH <7.35, or alkalotic with a pH >7.45?

Step 2

Evaluate the PaCO2. Is it normal, between 35 and 45 mmHg? If it is <35, it indicates an alkaline condition. If it is >45, it indicates an acidic condition.

Step 3

Evaluate the HCO3. Is it normal, 22 to 28 mEq/L? If it is >28, it indicates an alkaline condition. If it is <22, it indicates acidic condition.

Step 4

Which component matches the pH acid-base state, the PaCO2 or the HCO3? Finally, decide if the patient has respiratory acidosis or alkalosis, or metabolic acidosis or alkalosis.

Here are some additional tips:

If an abnormal pH exists, the body will try to correct it. The respiratory system starts CO2 correction quickly, within minutes. HCO3 correction via the kidneys is much slower, taking hours to begin.

If the pH is abnormal, one value either PaCO2 or HCO3 is abnormal and one value is normal, the condition is uncompensated. The other value has not started to neutralize the abnormal pH.

If the pH is abnormal and both the PaCO2 and HCO3 are abnormal, the condition is partially compensated. The body has started neutralizing the abnormal pH but compensation is not complete.

If the pH is normal and both PaCO2 and HCO3 are abnormal, the condition is compensated.

If the pH, PaCO2 and HCO3 are normal and were previously abnormal, the ABG is called corrected.