Principles of acid base balance

The purpose of this handout is to educate the student on basic principles of acid base balance. To give a systematic approach to interpretation and understanding of arterial blood gases and appropriate care for the patient who is having a blood gas taken. It is intended that the student will learn from this package but also be encouraged to source other material to broaden their understanding of acid base balance. It is intended that this learning packet will complement their experiences with help of an understanding mentor, who will assist them with questions raised both within themselves and within the book.

An arterial blood gas measures the acidity of the blood, the levels of carbon dioxide and levels of oxygen. The blood is taken from an artery prior to the blood distributing the oxygen from blood cells to the body tissues.

The values the gas will show are:

Partial pressure of oxygen (PaO2) this measures the pressure of oxygen dissolved in the blood Edwards (2009) say this can indicate how good respiratory system is functioning. This can indicate oxygen saturation and how well oxygen can move from the lungs to the blood

Partial pressure of carbon dioxide (PaCO2) this measures how much CO2 is dissolved in the blood and how well it can move from the blood to the lungs (and out of the body). Foxall (2008) explains that co2 mixed with water turns in to carbonic acid that the lung must excrete to prevent an acidosis.

Bicarbonate (HCO3) Bicarbonate is the form in which a large amount of acid is removed from the cells Schilling (2008) says about 70% is removed from tissues and bicarbonate can be measured as either actual or standard bicarbonate. The standard which is the more important value is obtained by using a PCo2 of 5. 6 kPa as a reference for the amount of CO_2 in the body.

Base excess (B. E.) Springhouse (2008) explains that the base excess indicates the amount of excess or lack of bicarbonate in the circulatory system it can be a negative number indicating too much acid or a positive number indicating too much base. It normal range is -2 to +2

Introduction

Skinner (2005) and Adam (2009) concur in that arterial blood gas analysis is an essential part of diagnosis and management a patient’s ventilation therapy and their acid base balance. Skinner continues to say the usefulness of this intervention is dependent on the ability of the health professional to analyse and interpret the individual aspects of the gas.

The intention of this learning packet is to introduce the learner to the individual aspects of a blood gas, and there meaning. Additionally it hopes to show how to bring these values together to formulate a decision on the patient’s condition and suggest options for treatment.

Common reasons for blood gas analysis are:

- To diagnose and assess existing lung function.
- To review treatment for lung disease and evaluate its effectiveness.
- To assess if extra oxygen is required for a patient or if further support is required (CPAP, BIPAP or PPV).

- To measure the acid base level in patient's where it is compromised. Patient would include renal patients', patient with heart failure, severe infected patients' uncontrolled diabetes or individuals who have taken an overdose.

Preparing the patient.

Explain to the patient that they are having a blood test from their artery. It is likely to be taken from a radial artery.

Nettina (2005) Describes a test to assess the puncture site prior to puncture called the Allen's test procedure. This will evaluate the blood circulation in the hand and whether it is appropriate to use the radial artery for puncture. The site will be cleaned with alcohol and allergy status permitting anaesthetic agents will be applied to reduce discomfort, and increase possibility of success.

Dougherty (2008) suggests that the patient should be encouraged to breathe normally through the procedure and the doctor may ask for cessation of supplementary oxygen prior, to give a better understanding of the patients' present condition.

After the syringe is full, place gauze over the puncture site and apply pressure until bleeding has stopped. This may be some time if the patient is on blood thinners or has coagulopathy. Once bleeding has stopped apply a dry dressing but monitor for any further bleeding.

After the procedure there is a possibility of bruising although the longer pressure is kept on the puncture site the lower the risk. Some light headedness or nausea may occur during or after the blood draw. On rare occasions the needle may damage the artery or a nerve causing it to become blocked. As a result care must be taken with the wrist once blood draw has taken place.

How it feels

Dougherty explains that collecting arterial blood from a patient is a procedure that is often painful. It is more painful than the routine venous phlebotomy your patient may be used to. There are a number of reasons for this, arteries are often deeper than veins and surrounded by nerves.

Ideally the patient is given a local anaesthetic and the patient feels just a sting as the needle punctures the skin. Otherwise there is a sharp pain as the needle enters the artery.

If the procedure becomes protracted either by the practitioner having difficulty finding the artery or the artery is narrow the pain may more than brief. It is important to note that both pain and fear would cause the arteries to narrow so reassurance is important and if the practitioner continues to have difficulty you must advocate on the patients behalf since fear would impact on future successful arterial blood gas collection.

Questions

- What other sites could a patient have blood gases taken from?
- Can only arterial blood be used for blood gases? What values would be markedly different in a venous sample blood gas.
- Why would a patient emotional response make blood draw difficult how can we reduce the affects of this to cause a positive outcome

- What medications or disease process would make a patients' bleeding time prolonged after sampling?

Further reading

Royal Marsden clinical procedures manual 2008, Dougherty etal

Overview

The measurement of a blood gas will show a pH value. PH is a value the can range from 1 to 14 and is a measure of acidity or alkalinity of a substance. Springhouse(2008)explains in the blood stream the pH value is inversely proportional to the number of hydrogen ions in the blood. The fewer ions the higher the number (alkalosis) and vica versa, more ions would mean a lower number (acidosis). A solution with a pH of 1 is acidic and a solution of pH 13 would be alkalotic. A solution of pH 7 is called neutral since it is in the middle, it is neither acidic nor alkalotic, and water has a pH of 7.

Adams (2009) explains that the normal PH of the body ranges from 7. 35 to 7. 45. In order for normal metabolism to take place the body must maintain this fine balance at all times. He clarifies that if the pH level rises the blood is said to be alkalotic or acidic if it drops below 7. Hall (2009) says the ability of the body to function normally is impaired if the pH moves from these parameters. Hall also concludes that in acidosis the body's response to medication is muted, cardiac function is impaired since contractility and vascular response to catecholamine's is reduced. If the patients pH is raised then oxygenation is effected which interferes with neurological and muscle function. Adams points out that severe changes in pH that is above 7. 8 or below 6. 8 will interfere with basic cell function and respiration and if not corrected will result in death.

Below is a discussion on how the body regulates this delicate balance. We will elaborate on the processes the renal and respiratory systems use to buffer the body's processes to keep this fine balance.

The respiratory buffer system

Hinds (2008) explain that carbon dioxide (CO_2) is a normal by product of cellular metabolism. Carbon dioxide is carried in the blood to the lungs where excess CO_2 combines with water (H_2O) to form carbonic acid (H_2CO_2) in the blood. The blood pH will change according to the level of this acid in the blood. This fluctuation triggers either a rise or fall in respiration until the level of CO_2 is returned to the patients' base line. Hinds explain that this system is fairly rapid and can be triggered in a short space of time a few minutes in most cases.

The renal buffer system

Henessey (2007) simplifies the metabolic system explaining that the kidneys also maintain acid base balance by the excretion or retention of bicarbonate (HCO_3). As the pH rises HCO_3 is excreted and in return as the pH decreases HCO_3 is retained. Although an effective system the renal system is slow to respond to imbalances, requiring hours or days to attend altered pH.

Questions

If neutral pH is 7 why does the body require a mean of 7. 4 a slightly alkalotic environment to operate?

The notes above indicate the body's response to catecholamine's is muted what are these and why are they important?

Normal values

pH

7. 35 to 7. 45

PO2

11 to 13. 3 kPa

PaCO2

4. 8 to 6. 0 kPa

HCO3

21 to 28 mmol/l

Acid Base Disorders

Respiratory acidosis.

Henessy (2007) discussion on respiratory acidosis is defined as a pH less than 7. 35 with a Pco2 greater than 6. 0 kPa. This type acidosis is caused by a build up of CO2 which combines with water in the body to produce carbonic acid thus lowering the pH of blood. Driscoll (1997) says any condition that results in a reduction in ventilation can cause this type of acidosis.

Head trauma, which has inflicted damage to the respiratory centre leading to respiratory depression.

Sedatives, narcotics, neuromuscular blocking agents or anaesthesia, which can cause central nervous system depression.

Impaired respiratory muscle function related to spinal cord injury or neuromuscular disease.

Poor lung function such pneumothorax, pneumonia, atelectasis or bronchial obstruction.

Hypo inflation due to pain chest injury or abdominal distension.

Hasan (2009) simplifies the presentation of the signs and symptoms of respiratory acidosis are centred within the respiratory, cardiovascular and nervous systems. These symptoms can range from shallow breathing or dyspnoea to headaches or altered consciousness and irritability. If left unchecked these symptoms deteriorate towards drowsiness and coma.

Increasing ventilation support will correct this type of acidosis. The specifics of how this will be done is dependant on the mode of insult to the respiratory system. Edwards (2009) suggests ventilator support could be oxygen via a face mask, non invasive ventilation (N. I. V.) or positive pressure ventilation (P. P. V.). If medications are inhibiting respiratory function then reversal agents can be deployed whilst supporting the patients' respiratory needs. Pneumothorax and pain are problems that can be reversed promptly once the patients' condition allows. Marino (1997) say that if the patients symptoms or condition, cannot easily be resolved then it may be appropriate to ventilate the patient mechanically. Commonly patient's with respiratory acidosis are hypo ventilating, as a result they will benefit from supplemental oxygen but this only improves the quality of respiration; it does not in fact remedy the problem.

Respiratory Alkalosis

Respiratory alkalosis is defined as a pH greater than 7. 45 with a PaCO2 less than 4. 8 kPa. Any condition that causes hyper inflation can result in respiratory alkalosis. These conditions include,

Pain

Anxiety fear or panic

Medications which stimulate the respiratory system

Lesions in the brain affecting the respiratory centre

Increased metabolic demands such as fever sepsis or pregnancy.

Alkalosis will present cardiovascular or central nervous system disorder. Springhouse (2008) illustrates that presentations can be dysrhythmias and palpitations to numbness and confusion. Additional symptoms are dry mouth, blurred vision and titanic spasms of the arms and legs.

To resolve the alkalosis the cause of the hyper ventilation must be attended to. These patients are at risk of suddenly deteriorating, they have tachypnea and must be supported to reduce fatigue. If they become tired their own ability to ventilate adequately will be impaired leading to respiratory failure.

Questions

- What would be the signs and symptoms of a patient with a respiratory caused imbalance?
- Which kind of medications can cause an acidotic condition and what would be the reversal agents?
- In respiratory alkalosis why do patients suffer with tetany?
- What are the signs and symptoms of respiratory failure?

Metabolic acidosis

Metabolic acidosis is defined as a bicarbonate level less than 21mEq/L with a pH of less than 7. 35. Schilling (2008) explains metabolic acidosis is caused either by a deficit of base in the blood stream or an excess of acids other than CO2. Excessive bowel action such as diarrhoea and intestinal fistulas may cause decreased levels of base. Increased acids can be caused by a number of factors such as:

- Renal failure
- Diabetic ketoacidosis
- Anaerobic Metabolism
- Starvation
- Salicylate intoxication

Hall (2009) Signs and symptoms of metabolic acidosis are varied affecting numerous systems. The nervous system presents with headaches, dizziness leading to confusion or later coma. Dysrhythmias are common as conduction pathways are affected and low blood pressure due to desensitivity to catecholamines such as epinephrine. Marino (1997) elaborates to say the respiratory system will attempt to correct imbalances by breathing out more CO_2. Kussmaul respirations these are deep and laboured breaths. In the gastro intestinal tract nausea and vomiting is noted as well as warm flushed skin.

The Hinds (2008) says treatment of the metabolic acidosis is to resolve the cause, this invariably means an initial review of body systems and their function. By assessing each function and its efficiency, underperfused or hypoxic tissue beds can be identified. Hypoxemia can lead to generalised anaerobic metabolism, but hypoxia of a specific tissue bed will produce metabolic acids even if oxygenation (PaO_2) is normal. To reverse this acidosis perfusion must be restored which in turn will cease the anaerobic metabolism. Hinds warns that other causes of metabolic acidosis should be addressed after the possibility of hypoxia and poorly perfused tissue beds have been resolved or ruled out.

Metabolic alkalosis

Metabolic alkalosis is defined as a bicarbonate level of 28mEq/L with pH greater than 7. 45. Metabolic alkalosis obviously is the reverse of the previous condition deriving from an excess of base or a deficit of acid. Adam (2009) suggests that excessive base comes from ingestion of antacids, excess use of bicarbonate or lactate in dialysis. Low amounts of acid come from overuse of diuretics, gastric suction or protracted vomiting.

It presents through neurological signs and symptoms varying from light headedness to seizures and coma or musculoskeletal symptoms of weakness, muscle cramps and tetany. Other associated signs might be nausea and vomiting and respiratory depression. This is a relatively uncommon presentation and presents a challenge in treatment. Bicarbonate can be stimulated thought the kidneys by drugs such as Acetazolamide but it is a protracted therapy. Severe cases I. V. administration of acids may be used

Questions

- Which other value is closely linked with the metabolic state of the body? What does it signify?
- What signs and symptoms would a patient show who presented with a metabolic acidosis?
- In a very severe alkalosis state what I. V. acids could be administered?

Steps to Arterial Blood gas interpretation

There are simply 3 steps to interpreting a blood gas result and each must be done in order to prevent confusion and misdiagnosing your patient. The components are pH PaCO2 and HCO3 below are three steps and following are examples to assist you in interpreting them.

Step One

Review the pH initially is this normal or abnormal? If the pH is above 7. 45 it is alkalotic if it is below 7. 35 then it is acidotic.

Step Two

If the blood sample pH is altered then we must consider how this is being affected. Initially assess the PaCO2 this value will move in the opposite direction to the pH when there is a insult to the respiratory system. That is as the pH falls out of normal values the $PaCO_2$ rises from its normal limits. The reverse is true if the $PaCO_2$ falls then the pH will rise.

Step Three

The third step is to assess the HCO_3 value. If there is an altered metabolic function the HCO_3 will alter in a similar direction to the pH. As the HCO_3 value rises so will the pH and as one decreases so will the other.

Examples:

Using the table above and your knowledge you have gained try and diagnose the problems below.

Example 1

Mr Brown is a 72 year old man admitted with recent chest infection to the assessment unit. He is quite short of breath and has a strong cough his blood gas show the following information

Patient: John Brown

D. O. B. 01: 01: 38

PH – 7. 30

$PaCO_2$ – 8

HCO_3 – 25

Step one, assess the pH is it normal? It is not, it is low therefore it is acidotic.

Step two, assess the $PaCO_2$ is it normal? It is not, it is raised which is the opposite direction of the movement of the pH.

Step three, assess the HCO_3, is that normal? Yes it is within its normal range.

Reviewing the grid it can be seen the pH being low, the $PaCO_2$ raised and the HCO_3 normal shows a respiratory acidosis.

Example 2

Maria 29, who has a long history indigestion and reflux, has come to the drop in clinic with vomiting unresponsive to her usual medications and cramp in her hands. A routine blood gas shows the information below.

Patient: Maria Goode

D. O. B.: 01: 01: 1981

pH – 7. 51

$PaCO_2$ – 5. 5

HCO_3 – 35

Assess the pH, is it normal? It is high indicating alkalosis

Assess the $PaCO_2$ is it normal? It is normal

Assess the HCO_3 is it normal? It is raised, moving in the same direction as the pH.

Looking at the chart above a raised pH and a raised HCO3 would indicate a metabolic alkalosis state

Discussion on compensation

So far we have only looked at a simple blood gas scenarios, with only one system failing. As Hasan (2009) indicates that often if one system fails or falls out of normal range altering the pH the second system will activate and work harder to compensate to bring the pH back in to normal limits. This activity is called compensation.

Foxall (2008) describes that when a patient develops an imbalance over a period of time the body will naturally attempt to compensate. The lungs and the kidneys are the primary response mechanisms and so the body will try to resolve any metabolic or respiratory imbalance to return the pH to normal

There are varying degrees of compensation initially uncompensated, an altered pH with only one value out of normal range. Partially compensated blood gas, an altered pH value with both values out of normal range. Compensated blood gas, a normal pH value with possibly both values out of range.

Previous examples we looked at were simple uncompensated blood gases. Now let’s look at more advanced gases such as partial compensation.

To review these gases as before break the interpretation down in to three simple steps

Assess the pH, is the gas acidotic or alkalotic

Assess the PaCO2; is the PaCO2 a normal value? As reviewed before respiratory imbalances will move the pH in the opposite direction to which the PaCO2 moves when causing a primary imbalance. If the PaCO2 is moving in the same direction that is either increasing, or decreasing in value, then this would be a compensatory behaviour and it would indicate the primary insult is coming from the kidneys (metabolic). In a compensatory environment a decreasing PaCO2 would show the lungs are buffering by excreting excess acid by blowing off Co2 in order to equalise the balance of acids and return the pH to normal. Conversely a raised pH and raised PaCO2 would indicate a buffering response by the lungs which would reduce acid excretion in an effort to return to homeostasis. In summary, if there is evidence of compensation, but the pH has not yet arrived back into normal limits then it is only partial respiratory compensation.

Assess the HCO3. In our original uncompensated examples the pH and the HCO3 moved in the same direction when the primary insult was metabolic. Following our discussion above in compensatory behaviours the values will work counter to their normal presentation. So if the pH is decreasing when the HCO3 is increasing or decreasing when the pH is increasing this is a compensatory action therefore the primary insult is a respiratory one. The kidneys will hold on to or release HCO3 in response to the abnormal pH to equalise the acid in the body to return the body’s pH to normal

The essential difference between these two states is that they are on a journey towards normal from possibly uncompensated , to partially compensated, to fully compensated environment (normal pH). The body is always trying to correct the imbalance however successful, but the body will never over compensate. As can be seen from the above table the pH in fully compensated states is normal. Knowing which side of 7. 40 will help in determine the original imbalance that is now compensated.

More technical questions

Example 1

A patient enters the A&E who is known to the renal team. He has been having dialysis 3 times a week for a year but missed his last appointment. He is complaining of being unwell. A Routine blood gas show the following results

Using the same 3 steps we have used before:

Patient : George Philip

D. O. B. : 01: 01: 50

pH – 7. 31

PaCO2 – 3. 9

HCO3 – 18 Is the pH normal? The answer is no it is low therefore it is acidotic

Is the PaCO2 Normal? No this is also low. If the PaCO2 was causing the primary insult we would expect it to move in an opposite direction to the pH in this case it is not. We must conclude therefore that the primary insult is metabolic and the paCo2 is out of range in a compenstatory role. The lung are excreting CO2 to reduce the PaCO2 whereby return equilibrium and return the pH to normal.

Is the HCO3 normal? It is not it is low moving in the same direction as the pH. Therefore confirming what has already been said that the primary problem is metabolic.

If you review the tables above it can be seen that the primary problem is metabolic but the full diagnosis would be a partially compensated metabolic acidosis

Example 2

A lady walks in to her local surgery complaining of shortness of breath she is a long term smoker. A routine blood gas shows the following results

Patient: Jane O’Brien

D. O. B. : 01: 01: 62

pH – 7. 35

PaCO2 – 7. 2

HCO3 – 29Assess the pH is it normal? Yes it is, but the low side of neutral

Assess the PaCO2 is it normal? No it is raised an acidotic condition. If this is the primary problem we would expect the pH to move in opposite direction to the PaCO2.

Assess the HCO3 is it normal? No it is also high which is representative of an alkalotic state.

Although the pH is normal both elements are out of range showing there is full compensation being achieved. The pH is lower than 7. 40 which shows it is moving in the opposite direction as the HCO3 which show the initial insult was respiratory and that the kidneys are compensating by retaining bicarbonate

Her arterial blood gas would be interpreted as fully compensated respiratory acidosis

Example 3

A 42 year old man on the surgical unit with history of bowel obstruction has had N. G. on free drainage has become unwell. Routine labs were sent and the blood gas below:

Patient: Tom Jones

D. O. B. : 01: 01: 47

pH – 7. 44

PaCO2 – 7. 1

HCO3 – 34

Is the pH normal? Yes Raised within normal limits

Is the PaCO2 normal? No this value is also raised, so therefore even if this is a fully compensated state it was a metabolic imbalance in origin.

Is the HCO3 normal? No this is raised with two value out of range and the pH with in normal limits this is fully compensated gas with the pH raised in normal limits and the HCO3 raised this was an initially a metabolic alkalosis

This is a fully compensated metabolic alkalosis.

Example 4

David has arrived from a nursing home with altered consciousness into the A&E department. His initial labs showed a raised white cell count and this blood gas was taken

Patient: David Hawcroft

D. O. B. : 01: 01: 72

pH – 7. 32

PaCO2 – 8. 2

HCO3 – 32

Is the pH normal? No it is low therefore it is acidotic.

Is the PaCO2 with in normal limits? No it is raised which indicates that respiratory system is causing the primary insult.

Assess the HCO3 is that normal? No this is raised also indicating that because it is moving in an opposite direction to the pH it must be in compensation, confirming the insult is respiratory in nature.

Since both elements are out of normal limits there is evidence of compensation but since thepH is not achieved normal values it is considered only partial compensation, so this gas is a partially compensated respiratory acidosis

Primarily this book has been to discuss the relationship between respiratory and renal systems is maintaining the body's acid base balance. Arterial blood gases are used also to interpret blood oxygenation using the Po2 value. This value indicates the partial pressure of oxygen, the ability of oxygen to bind to haemoglobin and transfer to tissues, this ability can be affected by the acid state of the body. Below is a discussion on the Oxyhemoglobin Dissociation Curve which is a graph that plots the behaviour of oxygen in the blood comparing saturation against partial pressure and how acid base can affect it.

Oxyhemoglobin Dissociation Curve

The Oxyhemoglobin curve is a tool used to show the relationship between oxygen saturation and Pao2. Marino (1997)points out that the strength at which oxygen binds to the haemoglobin can vary depending on the disease state of the body. This in turn can affect the oxygenation of tissue beds or end organ perfusion. Adam(2009) simplifies the principle explaining that oxygen can bind too tightly which would which would inhibit of transfer of oxygen to tissues that needed oxygen or alternatively not bind tightly enough an oxygen is lost before it reaches these target cells. This relationship between the affinity of oxygen and the saturation is illustrated below with the Oxyhemoglobin curve.

As mentioned above there are a number of conditions or states than can affect this relationship essentially moving the graph left or right. A fever, acidosis or elevated PCo2 levels can cause reduced adhesion of the O2 molecule therefore the graph and its values appear to move to the right (A right shift). Where as if the body is alkalotic, hypothermic or a low PCo2 the graph will shift to the left which would indicate the blood is failing to release the oxygen through increased affinity

The curve can be used to assess Pao2 if the oxygen saturation is known. Shown in the illustration is a person with a saturation of 82%. If the curve has not shifted then that persons' Pao2 would be 51mm Hg. A value of 80mmHg could indicate hypoxemia. Correction of the patients oxygen level may be facilitated by improving oxygen delivery and resolving conditions affecting the curve.

Revision Questions

- What number indicates extreme acid on the pH scale?
- What is the range for pH in the blood?
- The kidneys compensate for acid base imbalances by excreting what substance?
- Which A. B. G value indicates an excess or insufficiency of sodium bicarbonate?
- What two values are compared on the Oxyhemoglobin curve?

Interpretation revision

pH 7. 33 PaCO2 8. 0kPa HCO3 31

pH 7. 49 PaCO2 5. 9 kPa HCO3 34

pH7. 37 PaCO2 5. 3 kPa HCO3 25

pH 7. 44 PaCO2 4. 0 kPa HCO3 16

pH 7. 27 paCO2 5. 5 kPa HCO3 15

Further reading

Mays DA (1995). Turn ABGs into child’s play R. N. 58: 1: 36-40

Foxall & Kesley (2008) Arterial Blood Gas Analysis: an easy learning guide M & K Publishing Keswick Cumbria U. K.