PICU Resident Self-Study Tutorial

Interpreting Blood Gases

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INTRODUCTION

Blood gases give us a huge amount of information regarding the patient's physiologic condition and are the best method available to assess a patient's oxygenation and ventilation. Blood gas interpretation is something that is initially very confusing, is usually poorly taught in medical schools, comes up hourly in the PICU and will be on ***every exam for the rest of your life.***

In this self-study tutorial, we will go over a basic method to examine blood gases in the PICU. There are many ways to do this, some more rigorous than others. This is a method that works for me and should cover everything that you will need to know for call in the PICU and for the Pediatric Board Exams. To make less wordy, I will only talk about arterial blood gases. At the end, I will briefly review the differences between arterial, venous and capillary blood gases.

QUICK & DIRTY BLOOD GAS INTERPRETATION

A simple four step approach:

1. Does the patient have an acidosis or alkalosis?
2. What is the primary problem (metabolic or respiratory)?
3. Is there compensation?
4. How's the oxygenation?

Does the Patient Have An Acidosis or Alkalosis?

Normal pH 7.35 to 7.45
- < 7.35 : acidosis
- > 7.45 : alkalosis

What is the Primary Problem (metabolic or respiratory)?

The pH determines the primary problem.

It would be extremely unusual for either the respiratory or renal system to overcompensate

Normal $PaCO_2$ 35 to 45 torr
- < 35 : respiratory alkalosis
- > 45 : respiratory acidosis

Normal Bicarbonate 22 to 26 mEq/L
- < 22 : metabolic acidosis
- > 26 : metabolic alkalosis

	pH	pCO_2	bicarbonate
Metabolic Acidosis	↓	normal	↓
Metabolic Alkalosis	↑	normal	↑
Respiratory Acidosis	↓	↑	normal
Respiratory Alkalosis	↑	↓	normal

For a primary respiratory disorder, pH and pCO_2 move in opposite directions

For a primary metabolic disorder, the pH and bicarbonate move in the same direction

Is There Compensation?

Compensation is the body's attempt to return the acid-base status to normal

If the primary problem is:	the compensation will be a:
respiratory acidosis	metabolic alkalosis
respiratory alkalosis	metabolic acidosis
metabolic acidosis	respiratory alkalosis
metabolic alkalosis	respiratory acidosis

Generally the respiratory system can compensate almost immediately for a primary metabolic disorder, but the kidneys take longer to compensate for a primary respiratory disorder

Expected Compensation

Acute Respiratory Acidosis

For every 10 torr increase in $PaCO_2$,

the pH should decrease 0.08 units

the bicarbonate should increase by 1 mEq/L

Chronic Respiratory Acidosis

For every 10 torr increase in $PaCO_2$,

the pH should decrease 0.03 units

the bicarbonate should increase by 3.5 mEq/L

Acute Respiratory Alkalosis

For every 10 torr decrease in $PaCO_2$,

the pH should increase 0.08 units

the bicarbonate should decrease by 2 mEq/L

Chronic Respiratory Alkalosis

For every 10 torr decrease in $PaCO_2$,

the pH should increase 0.03 units

the bicarbonate should decrease by 5 mEq/L

Metabolic Acidosis

Expected $PCO_2 = 1.5 \times \text{(bicarbonate)} + 8 \pm 2$

Metabolic Alkalosis

For every 10 mEq/L increase in bicarbonate,

the PCO_2 should increase by 6 torr

Putting It All Together- Expected Compensation

Calculating Expected Compensation can help you to determine if a patient has a simple disorder (either a primary respiratory or metabolic disorder with appropriate compensation) or if a patient has a mixed disorder.

Let's look at the following example…

<u>Putting It All Together- Expected Compensation (continued)</u>

Say you have a patient with bronchopulmonary dysplasia *(a situation never seen in the ICU),* on chronic diuretic therapy who has an ABG with a pH of 7.42, a PCO_2 of 65 and a bicarbonate of 41.

Let's approach this from the respiratory side first (patient with PCO_2 retention).
The expected metabolic compensation would be for a 3.5 mEg/L increase in bicarbonate for every 10 mm increase in PCO_2
So measured PCO_2 of 65 – normal PCO_2 of 40 = 25.
The expected compensation for the bicarb should be (2.5 x 3.5) + 24 = 32.75.
However, the measured bicarbonate in this patient is 41.
So this patient has a metabolic alkalosis that complicates the respiratory acidosis (probably due to diuretic use)

You could also approach this from the metabolic side first (too much bicarbonate)
The expected compensation would be PCO_2 retention, 6 torr for each 10 mEq/L increase in bicarbonate
Given a bicarbonate of 41, with a normal of 24: 41-24=17
Therefore the expected PCO_2 should be (1.7 x 6) + 40 = 50.2 torr
However, the PCO_2 is measured at 65 torr
So this patient has a respiratory acidosis that complicates the metabolic alkalosis (probably due to bronchopulmonary dysplasia)

So either way you look at it, this patient has a mixed respiratory acidosis and metabolic alkalosis.

"We have a new blood gas machine."

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How's the Oxygenation?

There are a number of different ways of assessing oxygenation by looking at the arterial blood gas. (For more details, see the Physiology of Oxygen Transport Tutorial). For the purpose of this tutorial, we will discuss three:

Alveolar-arterial Oxygen Tension Difference

Also known as the A-a gradient
Classic method of assessing difficulties in oxygenation
Not so quick
Normal A-a gradient is less than 50 torr.

$$\textbf{A-a gradient} = P_AO_2 - P_aO_2$$

Where the P_AO_2 is the Alveolar PO_2 and the P_aO_2 is the arterial PO_2.
The P_AO_2 is determined by:

$$P_AO_2 = (713 \times FiO_2) - (PaCO_2/0.8)$$

Oxygenation Index

Takes into account how much ventilation the patient is requiring
Used for criteria for ECMO
The higher the OI the worse, generally OI higher than 20 are bad.

$$OI = \text{Mean Airway Pressure} \times FiO_2 \times 100 / PaO_2$$

PaO_2/FiO_2 ratio

The quickest way to assess oxygenation
Used in many studies and as a criteria for ARDS
Normally, should be 500.
On room air, normal PaO_2 = 100. So, 100/0.21 = 500
A PaO_2/FiO_2 between 200-300 reflects diminished oxygenation, <200 is ARDS

A WORD ABOUT BASE EXCESS/BASE DECIFIT

You may hear these terms used instead of the bicarbonate. So when someone is rattling off a blood gas, they may report the pH, PCO_2, PO_2 and then the base excess/deficit (instead of the bicarbonate). Some prefer this term, rather than the bicarbonate, since on most blood gas machines, the bicarbonate is a calculated number from the expected compensation and pH (and not truly measured). This can make it difficult to do the expected compensation calculations outlined on page 3.

The base excess or deficit is approximately the difference from the normal bicarbonate. So, someone with a bicarbonate of 21 should have a base deficit of –3 and someone with a bicarbonate of 27 should have a base excess of +3. **In general, base deficits (negative) reflect a metabolic acidosis and base excesses (positive) reflect a metabolic alkalosis.**

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TYPES OF BLOOD GASES

There are three types of blood gases that you will see in the ICU: arterial, venous and capillary. In general, compared to arterial blood gases, a venous or capillary blood gas has a "normal" pH of is 7.30-7.40 and a "normal" PCO_2 of 40-50 torr.

TYPES OF ACID-BASE DISORDERS

Acute Respiratory Acidosis

- the $PaCO_2$ is elevated and pH is acidotic
- the decrease in pH is accounted for entirely by the increase in $paCO_2$
- Bicarbonate and base excess will be in the normal range because the kidneys have not had adequate time to establish effective compensatory mechanisms
- Causes
  - Respiratory Pathophysiology
    - airway obstruction, severe pneumonia, chest trauma/pneumothorax
  - Acute Drug Intoxication
    - narcotics, sedatives
  - Residual neuromuscular blockade
  - CNS disease or Head Trauma

Chronic Respiratory Acidosis

- the $PaCO_2$ is elevated with a pH in the acceptable range
- renal mechanisms increase the excretion of H^+ within 24 hours and may correct the resulting acidosis caused by chronic retention of CO_2 to a certain extent
- Causes
  - Chronic lung disease
  - Neuromuscular disease
  - Extreme obesity
  - Chest wall/airway deformity

Acute Respiratory Alkalosis

- the $PaCO_2$ is low and the pH is alkalotic
- the increase in pH is accounted for entirely by the decrease in $paCO_2$
- Bicarbonate and base excess will be in the normal range because the kidneys have not had sufficient time to establish effective compensatory mechanisms
- Causes
  - Pain
  - Anxiety
  - Hypoxemia
  - Restrictive lung disease
  - Severe congestive heart failure
  - Pulmonary emboli
  - Drugs
  - Fever
  - Thyrotoxicosis
  - Pregnancy
  - Overaggressive mechanical ventilation
  - Hepatic failure
  - Sepsis

Uncompensated Metabolic Acidosis

normal $paCO_2$, low HCO_3, and a pH less than 7.30
occurs as a result of increased production of acids and/or failure to eliminate these acids
respiratory system is not compensating by increasing alveolar ventilation (hyperventilation)

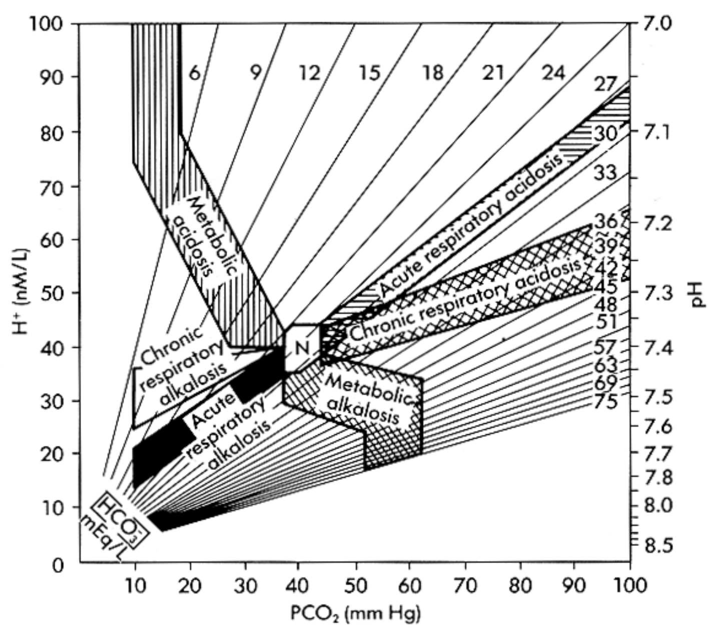
Compensated Metabolic Acidosis

$PaCO_2$ less than 30, low HCO_3, with a pH of 7.3-7.4
patients with chronic metabolic acidosis are unable to hyperventilate sufficiently to lower $PaCO_2$ for complete compensation to 7.4

Elevated Anion Gap	Normal Anion Gap
M ethanol	Hyperalimentation
U remia	Acetozolamide
D KA	Renal Tubular Acidosis
P araldehyde	Diarrhea
I nfection/INH/Inhalants	Ureterosigmoidostomy
L actic Acidosis	Carbonic anhydrase inhibitors
E thylene Glycol	
S alicylates	

CONCLUSION

I cannot recommend and clear and concise review of this topic. Nelson's Textbook of Pediatric actually states "It is relatively easy to diagnose a simple acid-base disorder correctly, based on the blood pH, PCO_2 and bicarbonate levels and using the following nomogram":



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Interpreting Blood Gases

If you know a good reference, please let me know, and I'll list it in the next printing of this tutorial.

Some of the better references are:

Marino PL. The ICU Book. Algorithms for acid-base interpretations, pages 415-426.

Rogers MC. Textbook of Pediatric Intensive Care 3rd Edition. Respiratory Monitoring: Interpretation of clinical blood gas values, pages 355-361.

Fuhrman B, Zimmerman J. Pediatric Critical Care Acid-Base Balance and Disorders, pages 689-696.

Bartlett R. Critical Care Physiology. Acid-Base Physiology, pages 165-173.

Three of the following review questions are heavily borrowed from the PREP series and the rest I made up. Good luck!