EMS1

Arthur Hsieh, MA, NRP
EMS News in Focus

A delicate balance: Understanding acid-base issues in EMS patients

A basic understanding of how acid-base imbalances can affect the patient's presentation can help make sense of conflicting symptoms

Aug 28, 2020

Editor's Note:

The human body must maintain itself within a very small pH window in order to properly function. It does so by utilizing an amazing acid/base buffering system which, when well understood by EMS providers, can help us better treat patients. How well do you understand acid-base balance? Take the quiz and test your knowledge.

The human body has tremendous capacity to maintain internal balance, or homeostasis, in serious, prolonged situations. However, there are several situations in which an imbalance that is left uncorrected can cause serious harm.

EMS providers are trained to recognize that a lack of oxygen or glucose will cause the patient to deteriorate in short order. While harder to detect in the field, derangements in the body's acid-base balance can also be catastrophic. However, a basic understanding of this critical concept can help develop a working field diagnosis and promote early interventions that could reduce morbidity.

WHAT ARE ACIDS AND BASES?

There are four distinct acid-base imbalances: respiratory acidosis, metabolic acidosis, respiratory alkalosis and metabolic alkalosis

Like all organisms, humans live within a water-based environment. Water contains hydrogen and oxygen (H_20). Water freely separates, or dissociates, into positively charged hydrogen ions (H^+) and negatively charged hydroxide ions (OH^-).

Hydrogen ions are a weak acid that interacts with a variety of chemical processes. The number of hydrogen ions within a water solution is expressed through a measurement called the power of hydrogen, or pH.

pH is measured using a negative logarithmic scale. This means two things. First, the smaller the pH number, the greater the concentration of hydrogen ions. Second, a change in whole number represents a tenfold change in the number of hydrogen ions. Taking those two concepts together, a fluid with a pH value of 5 is 10 times more acidic than a pH of 6; a pH value of 4 is 100 times more acidic than a pH of 6 (10x10).

The range of pH is 1 to 14. Water itself is neutral with a value of 7. A pH number less than 7 is considered acidic, while a number above 7 is considered basic. The human body rests in a slightly basic environment, functioning within a range of 7.35 to 7.45.

ACID-BASE BALANCE WITHIN THE BODY

In every moment of every day, mitochondria in the cells metabolize carbohydrates and fat to produce the energy necessary to power all of the body's processes. In doing so, carbon dioxide (CO_2) and water are produced.

In the presence of a specific type of enzyme, CO_2 combines with water to produce carbonic acid (H_2CO_3), which then quickly breaks down into H^+ ions and bicarbonate (HCO_3^-). Managing the level of H^+ so that it does not get out of control is the basis for acid-base balance.

STAYING IN ACID-BASE BALANCE

The body uses a series of systems to maintain acid-base balance. The production and breakdown of H_2CO_3 is known as buffering, or the buffer system. If the body's pH level is low (meaning that acid levels are high), H^+ is absorbed into the buffer system, maintaining balance. The opposite happens (H^+ is released) when the pH level becomes too high.

A classic chemical equation summarizes these interactions:

$$H^+ + HCO_3^- \Leftrightarrow H_2CO_3 \Leftrightarrow CO_2 + H_20$$

Specific carbonic acid enzymes facilitate these interactions such that as hydrogen ions levels rise, the equation "drives" to the right. Conversely, if carbon dioxide levels rise, the equation reverses and drives to the left. This means that high levels of carbon dioxide in the body will cause it to become acidotic as well.

The buffer system works immediately and continuously. As CO_2 is created by the cells, it combines with H_2O to form carbonic acid, which immediately separates into H^+ and HCO_3^-. H^+ is carried to the lungs on the hemoglobin molecules found in red blood cells. Once there, the buffer system drives back to the right, with CO_2 reforming and released out of the body during exhalation. This is the respiratory system control of acid-base balance.

If there is an increasing amount of carbon dioxide being produced, the brain triggers the respiratory system to increase the breathing rate (tachypnea) and depth (hyperpnea). Compared to the buffer system, the respiratory system takes a few minutes to hours to be effective. Even then, it only manages about 75% of an acid-base imbalance.

Any excess H_20 is excreted by the body through the renal system. The kidneys also eliminate excess hydrogen and bicarbonate ions as needed; they make bicarbonate as well. Compared to the buffer and respiratory system, the renal system is a long-term control system, taking hours to days to work.

THE BODY OUT OF BALANCE

There are two ways to look at acid-base imbalance. First, a patient is considered to be in acidosis when the pH of a blood sample is less than 7.35. If the pH value of the sample is greater than 7.45, the patient is in alkalosis. Second, acid-base imbalances are caused either by primary respiratory disorder, such as asthma or COPD, or by a primary metabolic disorder such as diabetic ketoacidosis.

When these two approaches are combined, it results in four distinct acid-base imbalances: respiratory acidosis, metabolic acidosis, respiratory alkalosis and metabolic alkalosis. Figure 1 shows these combinations.

---

pH < 7.35: Acidosis

	Respiratory Cause	Metabolic Cause
pH < 7.35: Acidosis	Respiratory Acidosis	Metabolic Acidosis
pH > 7.45: Alkalosis	Respiratory Alkalosis	Metabolic Alkalosis

pH > 7.45: Alkalosis

The way to best tell which state a patient is in is through laboratory testing, where a patient's blood gas sample is evaluated for its pH level, the amount of carbon dioxide (pCO_2), and the amount of bicarbonate available in the sample. A normal range of pCO_2 is 35-45 Torr; above 45 results in an acidotic state, while below 35 results in an alkalotic state.

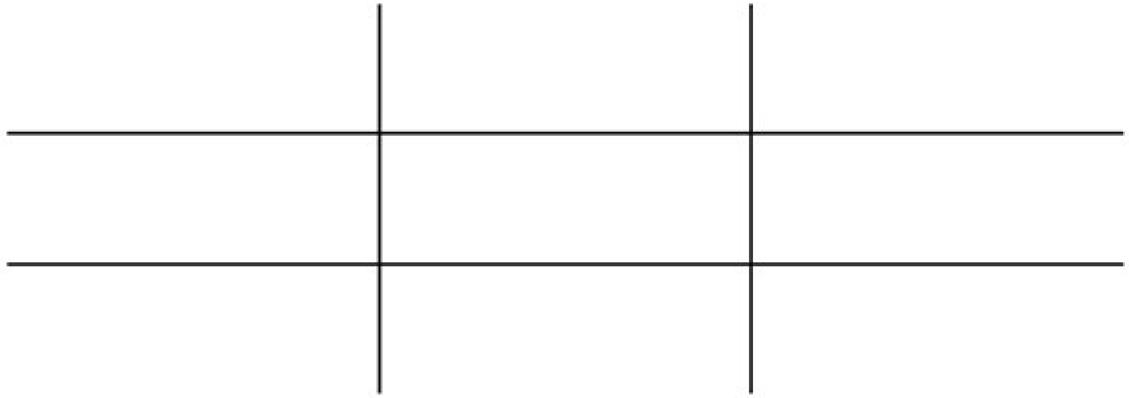
A normal level of bicarbonate is 22-28 mEq/L. A number below 22 indicates an acidotic state (not enough bicarb to buffer the hydrogen ions); a number above 28 indicates an alkalotic state (excess HCO_3^-).

While the measurement units might be confusing, just keep the numbers for each measurement in mind. A summary of these three measures is:

---

1. pH: acidosis < 7.35 - - - - 7.45 > alkalosis
2. pCO_2: alkalosis < 35 - - - - - - - 45 > acidosis
3. HCO_3: acidosis < 22 - - - - - - - - 28 > alkalosis

A simplified way of understanding blood gas values and determining the acid-base imbalance is by using a version of the old children's game tic-tac-toe. Begin by drawing a table like this:



Label the "board" as follows:

	Acidosis	Normal	Alkalosis
pH			
pCO_2			
HCO_3^-			

Look at the value of each measurement and determine if it's acid, normal or base. Here's an example:

An asthmatic patient with moderate shortness of breath was treated by EMS and transported to the emergency department. A blood gas analysis from the blood samples drawn in the field indicated that the patient's blood pH was 7.51, pCO_2 was 25, and HCO_3^- was 24. Oxygen saturation SPO_2 was measured at 89% at room air.

Using the summary of values from earlier, it appears that the pH was higher than normal, indicating alkalosis; pCO_2 was lower than normal, indicating alkalosis; and HCO_3^- was normal.

For each of your determinations, place an "X" into the corresponding square of the tic tac toe board.

	Acidosis	Normal	Alkalosis
pH			X
pCO_2			X
HCO_3^-		X	

From the grid it appears that the pH and PCO_2 values agree with each other, or line up in the same column. It means that this patient is in respiratory alkalosis. This makes sense; during the early stages of an asthma attack, the patient is breathing faster in order to increase oxygen levels in the blood. Breathing faster drops the amount of carbon dioxide; lower CO_2 results in alkalosis.

Let's say that the same patient is not getting better, despite treatment. His level of respiratory distress is greatly increased. Wheezing, which was heard earlier, is now more faint as bronchoconstriction and inflammation reduces airflow. A repeat blood gas shows that pH is now 7.28, pCO_2 is 65, and HCO_3^- is 31. If you evaluate these measurements, your board should look like this:

	Acidosis	Normal	Alkalosis
pH	X		
pCO_2	X		
HCO_3^-			X

The patient is now in respiratory acidosis. There is a metabolic compensation in the increased amount of bicarbonate as the body tries to compensate for the worsening acidosis.

SIGNS AND SYMPTOMS OF ACID-BASE IMBALANCE

Because most of the body's tissues are affected by an acid-base imbalance, the range and scope of the signs and symptoms is significant.

Respiratory acidosis: Caused by a primary breathing problem that results in CO_2 retention. Signs include headache, anxiety, restlessness, blurred vision. As carbon dioxide levels increase inside the body, the patient may lose consciousness.

Treatment is focused on restoring adequate ventilation through airway control via bag mask, continuous positive airway pressure, invasive airway interventions such as intubation and/or medications such as bronchodilators.

Respiratory alkalosis: Caused by a primary breathing problem that results in lower than normal CO_2. Signs and symptoms include dizziness, bloating, lightheadedness, muscle spasms in the hands and feet (carpopedal spasms), chest discomfort, numbness to the face and extremities (paresthesias).

Treatment is focused on resolving the underlying problem. In some cases, psychogenic hyperventilation may be the cause, but an undiagnosed hypoxic state may be forcing the body to breathe faster in order to maintain oxygen levels while causing CO_2 to decrease.

Metabolic acidosis: Caused by a primary metabolic problem that results in higher than normal levels of hydrogen ions. Signs and symptoms include nausea, vomiting and general weakness. A patient may breathe more quickly or deeply to try to compensate metabolic acidosis with a compensatory respiratory alkalosis. In more severe cases, hypotension, coma and cardiac dysrhythmias can develop, including ventricular fibrillation.

Like other forms of acid-base imbalance, treatment is directed at the cause of the imbalance, which can include conditions such as diabetic ketoacidosis, lactic acidosis, hyperkalemia, poor renal function and certain overdoses such as tricyclic antidepressants. In severe, life-threatening cases of metabolic acidosis, sodium bicarbonate may be administered intravenously as an aid to buffering.

Metabolic alkalosis: Caused by a primary metabolic problem that results in lower than normal levels of hydrogen ions or higher than normal bicarbonate ions. Signs and symptoms include headache, lethargy, muscle spasms (tetany), chest pain and seizures. Metabolic alkalosis is relative rare compared to the other acid-base states; causes include massive vomiting and/or diarrhea; large ingestion of alkalizing agents such as stomach antacids; hypokalemia, and hypovolemia.

A patient with severe metabolic alkalosis will require aggressive fluid resuscitation to reverse the hypovolemic state.

ACID-BASE BALANCE AND EMS

While point-of-care blood testing equipment is available for EMS use, most systems do not carry these tools due to cost and perceived limited value of the data as it relates to field care. However, as community paramedicine systems grow and evolve, there is likely to be a use for such laboratory testing.

However, having a basic understanding of how acid-base imbalances can affect the patient's presentation can not only refine the EMS provider's field impression of the severity of the situation, but also may help make sense of sometimes confusing or conflicting patient signs and symptoms.

For example, a 42-year-old female presents with tachypnea, tachycardia and anxiety. Her hands and face feel numb, and her hands are exhibiting carpopedal spasms. While a snap judgment might point to some form of psychogenic hyperventilation, the presentation might also be related to a pulmonary embolus or a metabolic disorder.

Another example would be a diabetic patient who has elevated blood sugar levels and is comatose. Thinking it was diabetic ketoacidosis, you might expect to see compensatory Kussmaul breathing – deep breathing with a longer expiratory phase to excrete more carbon dioxide. Instead, the patient appears to be breathing normally.

While this does not eliminate DKA as the underlying cause, it does raise the suspicion that the patient is experiencing hyperosmotic, hyperglycemic non-ketotic syndrome.

These are but two examples of how a basic understanding of acid-base balance can refine an EMS provider's field impression and treatment plans. A well-developed medical history may broaden the suspicion that other issues are involved in a complex patient presentation and result in a more efficacious treatment and transfer plan.

Test your knowledge: **How well do you understand acid-base issues in EMS?**

This article was originally posted on June 15, 2017. It has been updated.

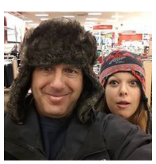
About the author

Art Hsieh, MA, NRP teaches in Northern California at the Public Safety Training Center, Santa Rosa Junior College in the Emergency Care Program. An EMS provider since 1982, Art has served as a line medic, supervisor and chief officer in the private, third service and fire-based EMS. He has directed both primary and EMS continuing education programs. Art is a textbook writer, author of "EMT Exam for Dummies," has presented at conferences nationwide and continues to provide direct patient care regularly. Art is a member of the EMS1 Editorial Advisory Board. Contact Art at Art.Hsieh@ems1.com and connect with him on Facebook or Twitter.

Tags › Capnography • Diagnosis • EMS Education • EMS Training • Evergreen • Medical / Clinical • Patient Assessment • Patient Care • Respiratory Distress

JOIN THE DISCUSSION

Please sign in or register to write your own comments below.
Before commenting, please read EMS1's Commenting Policy



Posted by **MEDICRICCI** Sep 2, 2019 at 7:48 PM

Hi there. I misunderstood this for years, but in a nutshell, acidosis and acidemia are different. So are alkalosis and alkalemia. This plays a role in CO2 monitoring. The term acidemia describes the state of low blood pH, while acidosis is used to describe the processes leading to these states. ... Acidemia is said to occur when arterial pH falls below 7.35 (except in the fetus – see below), while its counterpart (alkalemia) occurs at a pH over 7.45. For CO2 monitoring, this is a critical difference. A person in respiratory acidosis is blowing off a lot of CO2, and ditto for a person who is using

respiratory compensation for metabolic acidosis. Once bicarbonate levels fall to low levels, there is no buffer to use for further compensation. The exhaled CO2 levels drop as does the pH of the blood, i.e. the respiratory compensation method has failed, and acidemia is the result. Thankfully I learned this as it explained what had seemed to me a contradiction in gas values and pH. Here are a quick couple of references.
https://www.ncbi.nlm.nih.gov/books/NBK482146/   and https://www.anaesthesiamcq.com/AcidBaseBook/ab3_1.php

0

Posted by **evlynjoy651**   Feb 26, 2019 at 10:06 PM

how is acidosis and alkalosis treated/controlled

0

LATEST PRODUCT NEWS

- Pa. governor announces PPE stockpile to prepare for potential virus resurgence
- Will you be vaccinated for COVID-19? 5
- A DOPE approach to capnography
- 3 Ind. first responders awarded for saving FF at house fire
- What has your agency implemented to prepare for COVID-19 surges as well as the emergence of future pandemics?

MORE PRODUCT NEWS ›

PRODUCT ORIGINALS

- What has your agency implemented to prepare for COVID-19 surges as well as the emergence of future pandemics?
- 8 fall prevention tips for EMS providers to share with friends, family, and patients
- How is your organization shifting public-facing events?
- A delicate balance: Understanding acid-base issues in EMS patients 2
- Risk-taking and the virtual EMS classroom

MORE PRODUCT ORIGINALS ›

Copyright © 2020 EMS1. All rights reserved.