The Art and Science of Infusion Nursing

Natalie A. Masco, DNP, RN, FNP-C

Acid-Base Homeostasis

Overview for Infusion Nurses

ABSTRACT

Acid-base homeostasis is essential to normal function of the human body. Even slight alterations can significantly alter physiologic processes at the tissue and cellular levels. To optimally care for patients, nurses must be able to recognize signs and symptoms that indicate deviations from normal. Nurses who provide infusions to patients—whether in acute care, home care, or infusion center settings—have a responsibility to be able to recognize the laboratory value changes that occur with the imbalance and appreciate the treatment options, including intravenous infusions.

Key words: acid-base imbalance, arterial blood gas, infusion nursing, metabolic acidosis, metabolic alkalosis, respiratory acidosis, respiratory alkalosis

D.J., a 24-year-old male, presented to the hospital following a serious motor vehicle collision. He suffered a head injury and multiple internal injuries that required admission to the intensive care unit. D.J. developed acute kidney injury and received rapid-volume resuscitation with 0.9% sodium chloride. In the following days, he experienced multiple seizures requiring intubation for airway protection and large doses of intravenous (IV) lorazepam. He subsequently was placed on IV phenobarbital. Despite management of the kidney injury and seizures, the patient continued to demonstrate hyperkalemia and muscle twitching. Arterial blood gases obtained throughout this time showed alteration in acid-base balance. Acid-base homeostasis must be maintained in a narrow range for the body to function normally. Even slight changes can significantly alter physiologic processes at the tissue and cellular levels, as well as the pharmacokinetics of infused products. Nurses must be able to recognize possible causes and signs of acid-base imbalance that can indicate deviations from normal. In this article, the physiology of acid-base homeostasis will be addressed as well as the impact of acid-base imbalance related to patient care, including infusion therapy.

Author Affiliation: Wegmans School of Nursing, St. John Fisher College, Rochester, New York.

Natalie A. Masco, DNP, RN, FNP-C, has more than a decade of clinical practice in the acute care setting. Dr. Masco is an assistant professor at the Wegmans School of Nursing at St. John Fisher College in Rochester, New York, and is the coordinator of the Family Nurse Practitioner Program.

The author has no conflicts of interest to disclose.

Corresponding Author: Natalie A. Masco, DNP, RN, FNP-C, St. John Fisher College, Wegmans School of Nursing, 3690 East Ave, Rochester, NY 14618 (nmasco@sjfc.edu).

DOI: 10.1097/NAN.0000000000000187

FOUNDATIONAL CONCEPT OF pH

When discussing acid-base homeostasis, it is important to start with the definition of pH. pH is defined as the negative logarithm of the hydrogen ion concentration; it reflects the degree of acidity or alkalinity of an environment.[1] The normal hydrogen ion concentration of the blood is quite small, estimated at 0.0004 mEq/L. This measure is documented as a pH of 7.40. The normal range of blood pH for adults is 7.35 to 7.45.[2] Normal cellular metabolism continually releases acids to be excreted from the body to prevent the fluids from becoming too acidic. When a change in hydrogen ion concentration occurs and the body is unable to counteract the extreme using chemical buffers, respiratory regulation, or renal regulation, the pH of the body fluids becomes abnormal and cellular function is impaired. An increase in hydrogen ion concentration results in acidity within the body. Acidemia is defined as a blood pH of less than 7.35.[3] A pH of 6.9 or less in the body is incompatible with life and may result in death.[4] Likewise, a decrease in hydrogen ion concentration results in alkalinity. Alkalemia is defined as a blood pH of 7.45 or greater.[3] A blood pH of 7.8 or greater is incompatible with life and may result in death.[4] Figure 1 shows the acid-base continuum.

Death	Acidosis	Normal	Alkalosis	Death
pH 6.9 or less	pH <7.35	pH 7.35- 7.45	pH >7.45	pH 7.8 or greater

Figure 1 Acid-base continuum in the human body.

FINDING THE BALANCE: HOMEOSTASIS

Homeostasis refers to the automatic, self-regulating processes necessary to maintain the normal state of the intracellular/extracellular environments, despite changes in the environment.[5] The body has 3 lines of response to maintain pH homeostasis: chemical buffers, respiratory regulation, and renal regulation. The method by which the body attempts to achieve homeostasis is dependent on a number of factors: (1) the length of time of the imbalance, (2) the baseline function of the organs involved in achieving homeostasis, and (3) the underlying condition resulting in the imbalance.[5]

CHEMICAL BUFFERS: FIRST-LINE RESPONSE

Chemical buffers are elements that help maintain a near consistency of the pH of fluids by preventing an increase or decrease in the hydrogen ions.[5] Buffers act to change strong acids into weaker acids or to bind to acids to neutralize their effects.[2] Buffers take action immediately in the setting of imbalance, and potential changes in pH are adjusted. It is for this reason that chemical buffers are the first line of defense against pH imbalance. Chemical buffers can be found in the extracellular fluid, the intracellular fluid, the urine, and within erythrocytes. There are 3 individual buffers in the body: (1) carbonate/carbonic acid buffers, (2) phosphate buffers, and (3) plasma protein buffers. Plasma protein buffers are most plentiful in the body; however, the carbonic acid buffers are considered to be most important in relation to the respiratory system.

Bicarbonate buffers are imperative to maintaining homeostasis. Bicarbonate ions and carbonic acid are normally in chemical equilibrium in the extracellular fluid. When significant amounts of both carbonic acid and bicarbonate are present, a buffer is formed.[4] Under normal circumstances, there is much more bicarbonate present in the body than carbonic acid, with a ratio of 20 to 1.[4] This is consistent with the body's needs as more acids are produced as part of cellular function. The blood with its high base concentration is able to neutralize the metabolic acids produced. If the body becomes too acidic, the bicarbonate buffers take up excess hydrogen ions released by the acid to form carbonic acid. Through the action of the enzyme carbonic anhydrase, the carbonic acid is broken down into carbon dioxide and water, neutralizing the excess acid.[4] Conversely if the body is too alkaline, the carbonic acid, in conjunction with the bicarbonate buffers, will form bicarbonate and hydrogen ions. The body then will reabsorb the excess hydrogen ions to achieve a normal pH.

RESPIRATORY REGULATION: SECOND-LINE RESPONSE

The respiratory system is the body's second defense against acid-base imbalance.[4] All cells continually produce carbon dioxide. Carbon dioxide combines with water molecules to form carbonic acid. The body alters the rate and depth of respiration to make needed adjustments in the acid-base regulation. The respiratory system responds within minutes of imbalance and reaches maximum effectiveness in hours.[4]

The body's ability to use respiratory compensation is dependent on normal function of all components of the respiratory system. Chemoreceptors and respiratory neurons in the brainstem must be functioning optimally. It is important to recognize that this mechanism responds more slowly with aging. Respiratory regulation also depends on the motor nerve innovation of the respiratory muscles, including the diaphragm. In addition, the chest wall, airways, lungs, and pulmonary circulation must be functioning normally if respiratory regulation is to work effectively.

The rate and depth of respiration are influenced strongly by chemoreceptors that sense alteration in the partial pressure of arterial carbon dioxide and hydrogen in the blood.[6] If too much carbonic acid accumulates in the blood of a healthy person, hyperventilation will occur. The rate and depth of respiration increases and excess carbonic acid is exhaled in an attempt to correct the pH imbalance. If too little carbonic acid is present in the blood, the rate and depth of the respiration decrease, and hypoventilation occurs. This will result in retention of carbon dioxide until it is once more present in normal amounts in the body.

RENAL REGULATION: THIRD-LINE RESPONSE

Cells continually produce metabolic acids during normal metabolism. The function of the kidneys is to

excrete all acids from the body, with the exception of carbonic acid, which can only be excreted by the lungs through exhalation. If metabolic acids begin to accumulate in the blood, the kidneys compensate by increasing acid excretion. If alkalemia occurs, the kidneys slow their excretion mechanism to allow acid to accumulate in the blood to normal levels. Given the complex nature of this process, renal regulation takes 2 to 3 days to respond maximally to an acid-base imbalance; however, it can respond indefinitely for chronic imbalances.[4]

The kidneys have several mechanisms to achieve acid excretion. Fluid filtered from the blood enters the glomerular capsule at the beginning of the nephron.[4] Renal tubular fluid passes through the nephron to become urine. The epithelial cell lining of the renal tubule acts as a filter. This allows the cells to secrete certain substances into the renal tubular fluid for excretion and move other substances into the interstitial fluid for retention in the body. At the proximal tubules in the kidney, renal tubular epithelial cells excrete metabolic acid by secreting hydrogen ions into the tubule lumen. For each hydrogen ion that is secreted into the renal tubular fluid, 1 bicarbonate ion is moved into the interstitial fluid. The fluid filtered from the blood at the glomerulus contains many bicarbonate ions. Most or all of the bicarbonate ions are reabsorbed into the blood during secretion of hydrogen ions.

Renal tubular cells are able to secrete additional hydrogen ions into the tubular fluid to aid in removal of large amounts of hydrogen ions from metabolic acid. Once the hydrogen ions are in the renal tubular fluid, they combine with other substances: bicarbonate ions, phosphate urine buffers, and ammonia.[4] Bicarbonate ions and phosphate urine buffers are present in the glomerulus. When the kidneys need to excrete excess hydrogen ions, renal tubular cells increase their production of ammonia. Hydrogen ions combine with ammonia produced by renal tubular cells. Ammonia is a gas that moves easily into the renal tubular fluid when it combines with hydrogen ions to become ammonium ions. Ammonium ions are non-lipid soluble and do not easily cross from the renal tubular fluid back into the blood, resulting in excretion.

Although the kidneys are unable to excrete carbonic acid, they can compensate for carbonic acid imbalances by adjusting the excretion of metabolic acids.[7] By creating a deficit of another form of acid, the body can accommodate the larger amounts of carbonic acid. This assists in keeping the pH of the blood from becoming too abnormal. If a deficit of carbonic acid in the blood is prolonged, the kidneys will decrease the excretion of metabolic acids. As the metabolic acids accumulate in the blood, they will compensate for the lack of carbonic acid and return the pH of the blood toward normal.

WHAT HAPPENS WHEN HOMEOSTASIS FAILS?

If the body is unable to achieve or maintain homeostasis for the amount of time and degree needed by the body, clinical decompensation occurs. The rate of decompensation depends on the degree of reserve and one's baseline organ function. For the very young, the very old, and those with chronic disease, this decompensation can occur more quickly. On the other hand, normal, healthy adults can use their compensatory mechanisms for a period of time before failure ensues.

Acid-base homeostasis, as well as the degree and type of compensation, are measured in the blood with an arterial blood gas test.[2] Using these laboratory tests, it can be determined if there is an excess or deficiency in hydrogen ions, and the organ system involved in the imbalance or compensation. The lab values of particular interest to acid-base imbalance are the pH, arterial partial pressure of carbon dioxide ($PaCO_2$), and bicarbonate (HCO_3-). Figure 2 lists the normal range of arterial blood gas values. The pH is a measure of the hydrogen ion concentration.[2] The $PaCO_2$ is a measure of carbon dioxide in the blood and can aid in determining if the imbalance originates in the respiratory system or if the respiratory system is compensating for a metabolic imbalance in the body.[2] Conversely, HCO_3- can determine if the cause of the imbalance is from a metabolic etiology or if the metabolic system is compensating for a respiratory imbalance in the body.[2] Table 1 provides an overview of acid-base imbalances, compensatory mechanisms, and laboratory values.

Metabolic Acidosis

Metabolic acidosis results from a relative excess of acid in the body.[8] This may be caused by an increase in acid, a decrease in base, or a combination of both. Clinical conditions that result in an increase in acid in the body include diabetic ketoacidosis, starvation, alcoholism, severe hyperthyroidism, severe infection, burns, circulatory shock with tissue anoxia, and oliguric renal failure.[8] The ingestion of excessive acids in the form of purine-rich foods, omega-3 fatty acids, and citric acid can result in acidosis.[8] Clinical scenarios in which there is an excess elimination of bicarbonate ions from the body and may result in metabolic acidosis include diarrhea,

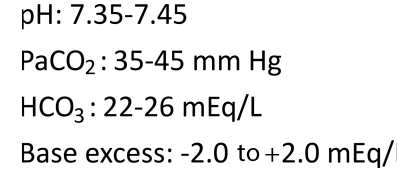

Figure 2 Arterial blood gases values for acid-base monitoring.

TABLE 1

Acid-Base Imbalance, Compensation, and Laboratory Values

	Lab Values	Compensation	Lab Values
Metabolic acidosis	Decreased pH Decreased HCO_3-	Respiratory: hyperventilation	Slightly decreased/normal pH Decreased HCO_3- Decreased $PaCO_2$
Respiratory acidosis	Decreased pH Increased $PaCO_2$	Metabolic: increased excretion of metabolic acids through the kidneys	Slightly decreased/normal pH Increased $PaCO_2$ Increased HCO_3-
Metabolic alkalosis	Increased pH Increased HCO_3-	Respiratory: hypoventilation	Slightly increased/normal pH Increased HCO_3- Increased $PaCO_2$
Respiratory alkalosis	Increased pH Decreased $PaCO_2$	Metabolic: decreased excretion of metabolic acid through the kidneys	Slightly increased/normal pH Decreased $PaCO_2$ Decreased HCO_3-

Abbreviations: HCO_3-, bicarbonate; $PaCO_2$, partial pressure of carbon dioxide; pH, the negative logarithm of the hydrogen ion concentration, reflecting the degree of acidity or alkalinity of an environment.

gastrointestinal fistulas, intestinal decompression, and renal tubular acidosis.[8]

When the pH of the interstitial and intracellular fluids declines, the protein structure and enzyme activity in the cells become altered, resulting in the signs and symptoms of metabolic acidosis. A decrease in pH of the cerebrospinal and interstitial fluid of the brain result in headache, confusion, drowsiness, or alteration in level of consciousness.[8] Additional symptoms include hypotension, hyperkalemia, muscle twitching, vasodilatation, and gastrointestinal disturbances.[8] Severe metabolic acidosis predisposes a person to fatal ventricular dysrhythmias, related to myocardial intracellular acidity, and a decrease in cardiac contractility.[8] The laboratory values of most importance to the nurse regarding metabolic acidosis are the pH and bicarbonate level. Both the pH and bicarbonate level are decreased with metabolic acidosis.

The body attempts to compensate for the metabolic derangement with respiratory regulation.[8] By increasing the rate and depth of respiration, the body excretes additional carbonic acid. Although hyperventilation does not remove metabolic acid from the body, it does change the ratio of bicarbonate ions to carbonic acid in a favorable direction. If compensation has been achieved, the lab values show a slightly decreased/normalized pH, a decreased HCO_3-, and a compensatory decrease in $PaCO_2$.

Respiratory Acidosis

Respiratory acidosis is a condition that tends to cause a relative excess of carbonic acid, resulting from impaired gas exchange or impaired respiratory function.[9] Impaired respiratory gas exchange of carbonic acid can occur with chronic obstructive pulmonary disease, pneumonia, severe asthma, pulmonary edema, obstructive sleep apnea, or acute respiratory distress syndrome.[9] The impaired gas exchange can be acute, chronic, or acute-on-chronic in nature. Inadequate neuromuscular function can be the cause of impaired respiratory function and result in respiratory acidosis. Guillain-Barré syndrome, acute chest injury, hypokalemic respiratory failure, severe kyphoscoliosis, or respiratory muscle fatigue can all result in excess carbon dioxide retention and respiratory acidosis.[9] Impairment of the respiratory control centers of the brain may also result from the use of respiratory depressant medications, including opioids and barbiturates, or from conditions such as central sleep apnea.[9]

Neurologic abnormalities, including blurred vision, tremor, vertigo, disorientation, restlessness followed by lethargy, and somnolence, are more likely to occur with respiratory acidosis than with other types of imbalances, as carbonic acid passes more easily through the blood-brain barrier.[9] Headaches result from dilation of the blood vessels in the brain, causing an increase in intracranial pressure.[9] Cardiac dysrhythmias can occur from hyperkalemia. Severe respiratory acidosis causes peripheral dilation and hypotension. Reflexive tachycardia can result, particularly if a cardiac dysrhythmia is also present.[9] The laboratory values of importance to the nurse regarding respiratory acidosis are the pH and $PaCO_2$. The pH would be decreased, and the $PaCO_2$ level would be increased.

The body attempts to compensate for the acid-base imbalance with the metabolic system by increasing the renal excretion of metabolic acid.[9] Although the

kidneys cannot excrete carbonic acid, their ability to excrete more metabolic acid changes the ratio of bicarbonate to carbonic acid in a favorable direction. If compensation has been achieved, the lab values would show a slightly decreased/normalized pH, an increase in $PaCO_2$, and a compensatory increase in bicarbonate.

Metabolic Alkalosis

Metabolic alkalosis is a condition that results from an increase of base, a decrease of acid in the body, or a combination of both, resulting in a relative deficit of any metabolic acid.[10] Contraction alkalosis occurs with mild to moderate extracellular fluid volume deficit and can be the result of high-dose diuretic use.[10] Thiazide and loop diuretics enhance the sodium chloride excretion in the distal convoluted tubule and the thick ascending loop, respectively. Metabolic alkalosis occurs from chloride depletion and by increased delivery of sodium ions to the collecting duct, which enhances potassium and hydrogen ion secretion.[10] Also with the diuresis, there is an increased renal excretion of acid with retention of bicarbonate. Metabolic alkalosis may also occur with excessive ingestion of bicarbonate. A person who self-medicates with large amounts of baking soda or bicarbonate-containing antacids for indigestion is at risk for metabolic alkalosis.[10] Conditions that result in a deficit of acid, such as prolonged or excessive vomiting or gastric suction through a nasogastric tube, can also result in metabolic alkalosis.

Clinical manifestations of metabolic alkalosis can include fatigue, dizziness, irritability, and restlessness followed by alteration in level of consciousness.[10] Neuromuscular excitability results from the increased interstitial pH and resulting excitability of nerve cell membranes. Alkalosis causes more ionized calcium to bind to albumin, causing an ionized hypocalcemia that contributes to increased neuromuscular excitability.[10] A person with metabolic alkalosis may experience tetany, tremor, paresthesia, muscle cramps, hypertonic muscle contractions, or seizures.[10] The laboratory values of importance to the nurse regarding metabolic alkalosis are the pH and bicarbonate level, both of which would be increased.

The body attempts to compensate for the metabolic alkalosis with respiratory compensation. By decreasing the rate and depth of respiration, the body retains carbonic acid. It is important to note that respiratory compensation is often incomplete for metabolic alkalosis as the need for oxygen drives ventilation, even though the decreased pH tends to depress it.[10] If compensation has been effective, the laboratory values would show a slightly elevated/normalized pH, an increased HCO_3-, and a compensatory increase in $PaCO_2$.

Respiratory Alkalosis

Respiratory alkalosis is a condition that results from a carbonic acid deficit. The etiology of this disturbance is hyperventilation related to hypoxemia, acute pain, anxiety/psychological distress/prolonged sobbing, or alcohol withdrawal.[11] Hyperventilation can also occur with abnormal stimulation of the respiratory neurons in the brainstem from meningitis, head injury, gram-negative sepsis, or salicylate overdose.[11]

The clinical manifestations of respiratory alkalosis arise from neuromuscular excitability. Increased extracellular pH increases membrane excitability in both central and peripheral neurons, while decreasing the availability of ionized calcium. Numbness and tingling in extremities results. Increase in the pH of the cerebral spinal fluid and cerebral interstitial fluid alters brain cell function. Cerebral vasoconstriction reduces blood flow to the brain and results in lightheadedness, lethargy, confusion, and seizures.[12] Other symptoms include nausea, vomiting, tachycardia, and hypotension. The laboratory values of importance to the nurse for respiratory alkalosis are the pH and carbon dioxide level. The pH would be increased, and $PaCO_2$ would be decreased.

The body attempts to adjust for this imbalance with metabolic compensation by decreasing the renal excretion of metabolic acids. As metabolic acid accumulates in the blood, the concentration of bicarbonate ions decreases as they are used to buffer the acids.[12] Because the carbonic acid concentration is already decreased, metabolic compensation for respiratory alkalosis involves balancing the bicarbonate ions to carbonic acid ratio, and thus the pH toward normal. If compensation is successful, the laboratory values would show a slightly increased/normalized pH, a decrease in $PaCO_2$, and a compensatory decrease in HCO_3-.

Mixed Acid-Base Imbalance

On occasion, 2 primary imbalances can exist in the same person. For example, a person may have pneumonia with resulting respiratory acidosis, requiring hospitalization. While admitted to the hospital and receiving antibiotics, she or he develops diarrhea and subsequent metabolic acidosis secondary to *Clostridium difficile* infection. Evaluation of laboratory values in this case would show a very low pH because 2 primary acidoses impair the effectiveness of the usual compensatory mechanisms. The usual compensatory mechanism for metabolic acidosis is to hyperventilate with increased excretion of carbonic acid from the body. With bacterial pneumonia, the effectiveness of the alveolar ventilation is already impaired and carbonic acid is retained, muting the ability of the body to compensate.

People with both metabolic and respiratory alkalosis often have a significantly high pH because the usual compensatory mechanisms are impeded by the concurrent acid-base disorder. An example could be seen in a patient with pneumonia who is prescribed chronic diuretics for heart failure. Respiratory alkalosis can occur with pneumonia secondary to dyspnea and decreased pulmonary compliance. The contraction metabolic alkalosis may be chronic, but given the acute respiratory imbalance it is more difficult for acid-base compensation to occur.

A person may also present with a mixed acid-base disorder.[4] A person with a head injury whose treatment includes hyperventilation to reduce intracranial pressure develops subsequent respiratory alkalosis. In addition, she or he could develop acute kidney failure, resulting in an excess of metabolic acids and a metabolic acidosis. In the case of a primary acidosis and primary alkalosis, the pH may be nearly normal, but alterations in the $PaCO_2$ and bicarbonate will be seen.

IMPLICATIONS FOR NURSES

Careful review of the clinical picture in conjunction with laboratory values is needed to determine the cause of the acid-base imbalance. As the professionals who monitor and assess patients, as well as administer medications that can either cause an acid-base imbalance or treat an existing imbalance, nurses have an important role in the health care team in the care and safety of patients. Metabolic acidosis and metabolic alkalosis are the conditions most affected by IV infusions. Reversal of the cause of the imbalance is of the utmost importance in reestablishing homeostasis.[13] Table 2 outlines acid-base imbalance and infusion-related etiology.

Metabolic acidosis can result from the administration of a number of infusions. Rapid IV fluid administration with 0.9% sodium chloride solution can result in hyperchloremic acidosis.[14] The increase in chloride load exceeds the kidney's capacity to generate equal amounts of bicarbonate.[15] For this reason, slow intravascular fluid replacement is preferred when clinically appropriate.[15] Infusion of acidic medications, such as ammonium chloride, can result in metabolic acidosis. Likewise, the infusion of hyperalimentation for patients who are unable to receive enteral nutrition may result in metabolic acidosis.[16] Propylene glycol is a common vehicle used as a drug solubilizer in various hydrophobic topical, oral, and IV compounds.[17] Propylene glycol is metabolized by the body into pyruvic acid and can result in metabolic acidosis. Propylene glycol is well tolerated in a relatively small total dose and is considered safe by the US Food and Drug Administration for use in drugs and cosmetics. However, adverse effects can occur when administered in moderate-to-high doses.[17] Medications that include propylene glycol include lorazepam and pentobarbital.[18] Case studies

TABLE 2
Metabolic Imbalance and Infusion-Related Etiology

Acid-Base Imbalance	Infusion-Related Etiology
Metabolic acidosis	Rapid sodium chloride infusion
	Ammonium chloride infusion
	Hyperalimentation infusions
	Infusions made with propylene glycol:
	• Diazepam, digoxin, esmolol, etomidate, hydrocortisone, lorazepam, nitroglycerin, pentobarbital, phenobarbital, phenytoin, trimethoprim/sulfamethoxazole[a]
Metabolic alkalosis	Intravenous administration
	• Penicillin
	• Carbenicillin
	Regional citrate anticoagulation
	• Hemodialysis
	• Continuous renal replacement therapies
	Sodium bicarbonate infusion
	Loop diuretics
	Thiazide diuretics
	Large-volume red blood cell transfusions

[a]*Data from NDT Plus.*[21]

have been reported of patients who required high doses of these medications for alcohol withdrawal and developed subsequent severe metabolic acidosis.[17]

Metabolic acidosis may be treated with infusions. Sodium bicarbonate is a systemic and urinary alkalinizer used to increase serum and urinary bicarbonate concentrations and raise the pH.[14] Alkalinizing agents such as sodium bicarbonate may be administered in the form of IV fluids, or as an injection in the case of emergencies.[19] The dosing is based on the clinical setting, blood pH, and serum bicarbonate levels. It is important to recognize that administration of bicarbonate products usually is unnecessary if kidney function is normal or near normal.[13] Tromethamine is a second agent used to prevent or treat metabolic acidosis.[20] Tromethamine combines with hydrogen ions to form bicarbonate buffers. Dosing is based on body weight and base deficit.

Metabolic alkalosis can result from a number of infusions. As discussed earlier, thiazide and loop diuretics can result in metabolic alkalosis. The IV administration of penicillin, carbenicillin, or other semisynthetic penicillins may cause hypokalemic metabolic alkalosis, as a result of distal delivery of nonreabsorbable anions with an absorbable cation such as sodium.[20] Metabolic alkalosis is more likely to develop in the presence of renal insufficiency. Metabolic alkalosis can result from regional citrate anticoagulation used in hemodialysis or continuous renal replacement therapies.[21] Citrate is infused in the blood inflow in the circuit to prevent clotting. Because the dialyzer does not remove citrate completely, a fraction of the infused citrate can reach systemic circulation where it is metabolized by the liver into bicarbonate. The accumulated bicarbonate alters the pH environment and can lead to metabolic alkalosis. Similarly, receiving massive blood transfusions, defined as replacement of a person's blood volume or 8 units of blood within a 24-hour period, can result in metabolic alkalosis secondary to the citrate in the blood products.[22,23]

The management of metabolic alkalosis depends on the underlying etiology and the patient's fluid volume status.[10] In the case of vomiting, an antiemetic should be administered. If continuous gastric suction is required, gastric acid secretion can be reduced with proton-pump inhibitors. In patients taking loop or thiazide diuretics, the dose can be reduced or the medication stopped if appropriate. Alternatively, potassium-sparing diuretics or carbonic anhydrase inhibitor such as acetazolamide can be added to correct the alkalosis. Hydrochloric acid infusion may be indicated in severe metabolic alkalosis or alternately when sodium chloride or potassium chloride cannot be administered because of volume overload or advanced renal failure.[10] Hydrochloric acid may also be indicated if rapid correction of severe metabolic alkalosis is warranted, with digoxin cardiotoxicity, cardiac arrhythmias, or hepatic encephalopathy. At other times, an infusion of ammonia chloride may be required to correct severe metabolic alkalosis related to chloride deficiency. Ammonia chloride is transformed by the liver into ammonia and hydrochloric acid. By releasing the hydrochloric acid, this can help improve the metabolic alkalosis. Another option for management of metabolic alkalosis is the initiation of hemodialysis with low-bicarbonate dialysate.

CONCLUSION

D.J., the 24-year-old patient introduced at the beginning of the article, experienced metabolic acidosis secondary to multiple causes: rapid sodium chloride infusion, administration of lorazepam, and lactic acidosis from sepsis. The nurse caring for this patient was astute to the etiology and importance of acid-base balance. At morning rounds, the nurse pointed out the number of variables that could be having an impact on D.J.'s acid-base imbalance. The nurse also noted that his symptoms of muscle twitching and hyperkalemia may have also been related to metabolic acidosis. In the days that followed, D.J.'s clinical status and lab values improved. D.J. made a full recovery and returned home a month after the accident. D.J. and his family were grateful for the excellent nursing care.

Acid-base balance is essential to normal cellular function. When there is loss of acid-base homeostasis, 1 of the following conditions occurs: metabolic acidosis, metabolic alkalosis, respiratory acidosis, respiratory alkalosis, or a mixed imbalance. These imbalances result not only from a variety of medical conditions but also from health care-related interventions, including IV infusions. As bedside care providers, nurses need to be aware of these imbalances. Early recognition and intervention can help achieve balance quickly and prevent worsening of a patient's condition.

REFERENCES

1. Clancy J, McVicar A. Short-term regulation of acid-base homeostasis of body fluids. *Br J Nurs*. 2007;16(16):1016-1021.
2. Fishbach F, Dunning M, eds. *A Manual of Laboratory and Diagnostic Tests*. 9th ed. Philadelphia, PA: Wolters Kluwer Health; 2015.
3. Lewis JL. Acid-base disorders. Merck Manual Web site. http://www.merckmanuals.com/professional/endocrine-and-metabolic-disorders/acid-base-regulation-and-disorders/acid-base-disorders. Updated May 2016. Accessed June 9, 2016.
4. Copstead LC, Banasik JL. *Pathophysiology*. 5th ed. Philadelphia, PA: Saunders; 2012.
5. Clancy J, McVicar A. *Physiology and Anatomy. A Homeostatic Approach*. 2nd ed. London, UK: CRC Press; 2002.
6. Clancy J, McVicar AJ. Intermediate and long-term regulation of acid-base homeostasis. *Br J Nurs*. 2007;16(17):1076-1079.
7. Gould B, Dyer R. *Pathophysiology for Health Professionals*. 4th ed. Philadelphia, PA: Saunders; 2014.

8. Thomas CP, Hamawi K. Metabolic acidosis. Medscape Web site. http://emedicine.medscape.com/article/242975. Updated December 18, 2015. Accessed June 9, 2016.
9. Byrd RP, Roy TM. Respiratory acidosis. Medscape Web site. http://emedicine.medscape.com/article/301574. Updated July 31, 2015. Accessed July 9, 2016.
10. Thomas CP, Yaseen S. Metabolic alkalosis. Medscape Web site. http://emedicine.medscape.com/article/243160. Updated May 19, 2015. Accessed June 9, 2016.
11. Adrogué HJ, Madias NE. Disorders of acid-base balance. In: Schrier RW, ed. *Atlas of Diseases of the Kidney*. Vol 1. Malden, MA: Wiley; 1999. http://www.kidneyatlas.org/book1/adk1_06.pdf. Updated 1999. Accessed June 9, 2016.
12. Byrd RP. Respiratory alkalosis. Medscape Web site. http://emedicine.medscape.com/article/301680. Updated July 31, 2015. Accessed August 20, 2015.
13. Whetsone Foster JG, Prevost SS. *Advanced Practice Nursing of Adults in Acute Care*. Philadelphia, PA: FA Davis; 2012.
14. Quinn A, Sinert R. Metabolic acidosis in emergency medicine. Medscape Web site. http://www.medscape.com/article/768268. Updated July 27, 2015. Accessed June 6, 2016.
15. Eisenhut M. Adverse effects of rapid saline infusion. *Arch Dis Child*. 2006;91(9):797.
16. Dounousi E, Zikou X, Koulouras V, Katopodis K. Metabolic acidosis during parenteral nutrition: pathophysiological mechanisms. *Indian J Crit Care Med*. 2015;19(5):270-274.
17. Yaucher NE, Fish JT, Smith HW, Wells JA. Propylene glycol-associated renal toxicity from lorazepam infusion. *Pharmacotherapy*. 2003;23(9):1094-1099.
18. Lexicomp Online, Lexi-Tox. Hudson, OH: Lexi-Comp, Inc; 2015; February 8, 2016.
19. Lexicomp Online, Lexi-Drugs. Hudson, OH: Lexi-Comp, Inc; 2015; July 7, 2015.
20. Lewis JL. Metabolic alkalosis. Merck Manual Web site. http://www.merckmanuals.com/professional/endocrine-and-metabolic-disorders/acid-base-regulation-and-disorders/metabolic-alkalosis. Updated May 2016. Accessed June 10, 2016.
21. Davenport A, Tolawni A. Citrate anticoagulation for continuous renal replacement therapy (CRRT) in patients with acute kidney injury admitted to the intensive care unit. *NDT Plus*. 2009;2(6):439-447.
22. Donaldson MD, Seaman MJ, Park GR. Massive blood transfusion. *Br J Anaesth*. 1992;69(6):621-630.
23. Emmett M, Szerlip H. Causes of metabolic alkalosis. UpToDate Web site. http://www.uptodate.com/contents/causes-of-metabolic-alkalosis.Updated October 9, 2015. Accessed June 10, 2016.

