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FEATURED ARTICLE

ABCs of ABGs: A Guide to Interpreting Acid-Base Disorders

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Abstract

Purpose: This objective of this article is to provide a useful resource on the assessment of arterial blood gasses (ABGs) for clinical pharmacists, pharmacy residents, and students.

Summary: Acid-base pathophysiology can be separated into metabolic or respiratory acidosis and alkalosis, as well as those disturbances that are compensated. This article provides readers with a stepwise approach for assessing ABGs, as well as offering actual case examples to familiarize the reader with the concepts of acid-base disorders. By the completion, the reader will have the tools necessary to assess any ABG that may be encountered in clinical practice.

Conclusion: Comprehension of acid-base pathophysiology is a complicated and overwhelming task for novice and experienced clinicians alike. Utilization of the stepwise approach proposed in this article will help clinicians at all levels of training assess and develop treatment options for any acid-base disturbance encountered in practice.

Key Words—acid-base, acidosis, alkalosis, arterial blood gas

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INTRODUCTION

The memories of pharmacy school that may be conjured by the words *acidosis* and *alkalosis* might very well cause facial flushing, lightheadedness, and nausea in the unfortunate individual who hears them spoken aloud. He or she may also recall having thoughts such as, "Is this stuff ever going to be useful?" during efforts to learn the Henderson-Hasselbach equation and memorize pK_as. Although acid-base pathophysiology seems complex, it contains important concepts that are used daily to optimize the pharmacotherapy of hospitalized patients.

When discussing any complicated process, it is best to start from a reference point—one that can be referred to whenever confusion arises. For acid-base disturbances, that reference point is the bicarbonate–carbon dioxide buffer system, shown in Equation 1.[1]

This buffering equation holds the basis for all acid-base physiology within the human body, and dissection of the equation will help form the basis for the remainder of this article. The processes that occur in the body drive this equation either to the left or to the right to maintain a normal pH. Think in terms of the left side of the equation occurring in the lungs and the right side occurring in the kidneys. Anytime hydrogen ions (H^+) are lost, the equation proceeds to the right. The lungs retain more carbon dioxide (CO_2) in the form of pCO_2 (partial pressure of CO_2 in the arterial blood) to convert CO_2 into carbonic acid (H_2CO_3). Carbonic acid is then converted to H^+ and bicarbonate (HCO_3^-), thereby replacing the lost H^+. Likewise, anytime hyperventilation occurs, the lungs are releasing pCO_2, thereby shifting the equation to the left. The body's compensatory mechanism for this loss in acid (pCO_2) is that the kidneys hold on to more H^+ (or excrete more HCO_3^-), thereby maintaining the pH at a "normal" level. However, an important distinction must be made here: pCO_2 and HCO_3^- are excreted independent of one another. If excess pCO_2 exists in the body, it cannot be excreted in the kidneys; rather, it must be exhaled by the lungs. Similarly, if there is an increase in H^+, the body cannot con-

Equation 1[1] $CO_2 + H_2O$ (water) $\leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

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vert it to pCO_2 for excretion in the lungs; it must be excreted by the kidneys.

All acid-base disturbances can be explained using Equation 1. Metabolic acidosis results from either an excess in H^+ or a deficiency in HCO_3^-. On the other hand, metabolic alkalosis results from an excess in HCO_3^- or a deficiency in H^+. Respiratory acidosis results from an excess in pCO_2, and respiratory alkalosis results from a deficiency in pCO_2. Primary metabolic disorders can be seen as disturbances in the serum HCO_3^- level, with compensation occurring via the respiratory route and reflected in the pCO_2 found in the arterial blood gas (ABG). Similarly, all respiratory disturbances are reflected in the ABG pCO_2 level, with compensation occurring metabolically as reflected in the serum HCO_3^- level. If only evaluating the laboratory values, it may be unclear at times which disturbance is causing the primary problem; thus, patient assessment plays a pivotal role in diagnosis. The cause of all acid-base disturbances can be determined by evaluation of electrolyte panels, ABGs, and patient assessment. This article provides a stepwise approach to assessing ABGs and offers actual case examples to familiarize the reader with the concepts of acid-base disorders. At the completion, the reader will have the tools necessary for assessing any ABG that may be encountered in clinical practice.

STEPWISE APPROACH FOR ASSESSING ARTERIAL BLOOD GASSES

For a clinician to interpret acid-base disorders, a basic understanding of the general concepts is necessary. Many hospital laboratories report ranges in normal laboratory values, such as pH 7.35 to 7.45 and pCO_2 35 to 45 mm Hg. A clinician must understand that under normal physiologic conditions, the human body attempts maintenance of homeostasis by keeping pH and pCO_2 as close to 7.40 and 40 mm Hg, respectively, as possible. Therefore, any variation from those values should be considered abnormal. Serum HCO_3^- levels, on the other hand, may vary from 22 to 28 mEq/L on a daily basis, based on a number of metabolic variables.

In an effort to maintain homeostasis, the human body must constantly compensate for either respiratory or metabolic changes. For example, when undergoing strenuous exercise, a number of changes occur within the body. First, as muscles become deprived of oxygen, they begin undergoing anaerobic metabolism. During this process, muscles produce lactic acid as a byproduct, thereby creating metabolic acidosis. In an effort to compensate and maintain a normal pH, the respiratory rate increases, causing ventilation of pCO_2 out of the body and resulting in respiratory alkalosis. Therefore, if an ABG is drawn during exercise activity, low HCO_3^- with an increased anion gap, as well as a low pCO_2, should be seen. Although the pH may be slightly acidic depending on the level of exercise, the respiratory center will continually compensate to prevent severe metabolic acidosis.

Thus, the topic of compensation is introduced. For any respiratory abnormality, the body compensates metabolically with changes in serum HCO_3^- through renal regulation. This compensation may take 3 to 5 days to begin, and in some cases, it may take up to a week to see the full compensation. Otherwise, the body compensates for any metabolic disorder through pulmonary regulation of pCO_2. This compensation occurs more rapidly than metabolic compensation, taking minutes to begin and with full compensation seen in hours.

One key factor for assessing ABG is determination of which primary acid-base disturbance exists and whether compensation has occurred. This is often a daunting task; however, if the clinician uses a stepwise approach (as outlined in Figure 1), both simple and complex acid-base disorders can be determined. First, and most importantly, assessment of the patient must be completed to determine what is physiologically occurring in the patient at that moment in time. Assessment of pH points the clinician in the direction of a primary acidosis or alkalosis. Second, assessment of pCO_2 and HCO_3^- will allow the clinician to differentiate the primary disturbance and whether compensation has occurred. The final step must only be made if a metabolic acidosis is present; that is, an anion gap and delta gap must be calculated to further differentiate the cause of the disturbance and better determine treatment options.

Example

A patient with new-onset, community-acquired pneumonia has a pH of 7.47, pCO_2 of 32 mm Hg, and serum HCO_3^- of 28 mEq/L. Using the first step in the approach for evaluating ABG (assessment of the patient), it is determined that the patient has a pulmonary process occurring (pneumonia). In addition, through assessment of the pH, it is evident that this patient has an alkalosis because the pH is greater than 7.40. Next, assessment of both the pCO_2 and the HCO_3^- (the second step) must be made to determine which is causing the acid-base abnormality. In this case, the pCO_2 is lower than normal and the HCO_3^- is on the high end of normal; this indicates that respiratory alkalosis

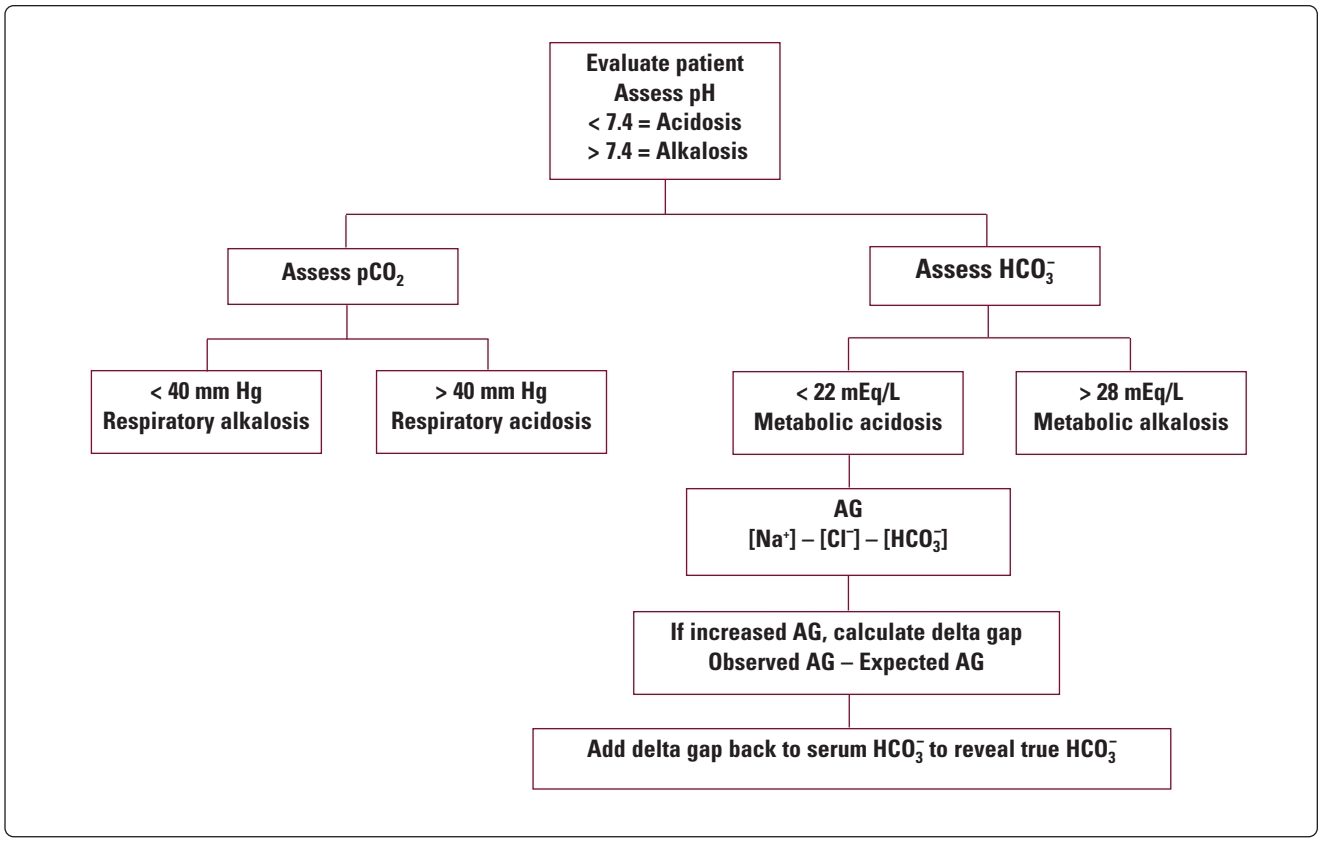

Figure 1. Stepwise approach for assessment of arterial blood gasses. AG = anion gap; Cl^- = chloride; HCO_3^- = bicarbonate; Na^+ = sodium; pCO_2 = partial pressure of carbon dioxide in the arterial blood.

is the major driving force for increase in pH. An interesting finding of this ABG is that one may expect a lower HCO_3^- as a compensatory mechanism for the respiratory alkalosis; however, there are 2 possible causes for this higher HCO_3^-. One explanation is that the patient's kidneys have not had time to compensate for the respiratory alkalosis; the other is that the patient may be volume contracted secondary to poor oral intake as a result of pneumonia, and thus, a contraction alkalosis may be occurring. Regardless, treatment of the pneumonia with antimicrobials, as well as volume expansion, should resolve the acid-base disturbance.

There are 5 acid-base disturbances that can occur in the human body: metabolic acidosis and alkalosis, respiratory acidosis and alkalosis, and mixed acid-base disturbances. All of these disturbances can be discovered using the stepwise approach for assessing ABGs.

METABOLIC ACIDOSIS

Case 1[2]

A 58-year-old woman has a 4-day history of lethargy, anorexia, abdominal pain, and nausea. Her medical history is positive for type 2 diabetes, for which she is taking metformin 500 mg twice daily, and osteoarthritis of the knees, for which she recently has been started on rofecoxib (unknown dose). The following detail her laboratory results on admission:

Electrolytes: sodium (Na^+) 140 mEq/L (136 to 145 mEq/L); potassium (K^+) 4.4 mEq/L (3.5 to 5 mEq/L); chloride (Cl^-) 100 mEq/L (98 to 106 mEq/L); HCO_3^- 5 mEq/L (22 to 28 mEq/L); serum urea nitrogen (BUN) 77 mg/dL (10 to 20 mg/dL); creatinine 9 mg/dL (0.5 to 1.2 mg/dL); glucose 112 mg/dL (70 to 110 mg/dL); lactic acid 178 mg/dL (5 to 20 mg/dL).

ABG: pH 6.8; pCO_2 20 mm Hg; partial pressure of oxygen (pO_2) 77 mm Hg.

Metabolic acidosis can be divided into 2 groups: that which is caused by an increased amount of unmeasured anions (increased anion gap metabolic acidosis) and that which is caused by a normal anion gap. In the case of an increased anion gap, several vari-

Equation 2[1,3] Anion gap = $[Na^+] - [Cl^-] - [HCO_3^-]$

Equation 3[4] Delta gap = Observed anion gap – Expected anion gap
Revealed HCO_3^- = Delta gap + Serum HCO_3^-

ables can lead to an increase in unmeasured anions. The acronym *KILU*—in which *K* signifies ketoacidosis (caused by diabetes, starvation, and chronic alcoholism); *I* signifies ingestions (typically from salicylates, ethylene glycol, and methanol); *L* signifies lactic acidosis; and *U* signifies uremia—can be used for remembering the potential causes of an increase in unmeasured ions. When faced with a serum electrolyte panel that reveals a lower-than-normal serum HCO_3^-, indicating metabolic acidosis, anion gap must be calculated by subtracting the difference in serum concentrations of the major cation (Na^+) and anions (Cl^- and HCO_3^-). See Equation 2 for this calculation.[1,3]

Under normal circumstances, the anion gap is 12 ± 4 mEq/L; however, negatively charged proteins, specifically albumin, can have a significant effect on the anion gap, such that a 1 g/dL drop in albumin will lower the anion gap by 2.5 mEq/L.[1,3] If the albumin of a patient is known, the normal anion gap can be calculated by multiplying the serum albumin by 3. This proves crucial when calculating the delta gap, which is the difference between the observed and the expected anion gap (see Equation 3).[4] The delta gap is used whenever an increased anion gap is observed to determine what the HCO_3^- level would be in the absence of unmeasured anions. That is, the result of the delta gap is added back to the measured HCO_3^-, and the result is the serum HCO_3^- without an anion gap (see Equation 3). This is especially useful in determining if sodium bicarbonate treatment should be administered to correct the acidosis.

From Case 1, the following can be calculated:

Anion gap
= 140 mEq/L – 100 mEq/L – 5 mEq/L
= 35 mEq/L

Expected anion gap
= 12 mEq/L
(No albumin is provided.)

Delta gap
= 35 mEq/L – 12 mEq/L
= 23 mEq/L

Revealed HCO_3^-
= 23 + 5 mEq/L
= 28 mEq/L

Based on this case example, the revealed, or adjusted, HCO_3^- excludes either an underlying, normal gap metabolic acidosis or metabolic alkalosis. The increased anion gap is secondary to unmeasured anions, in this case lactic acid, and secondary to metformin therapy in the setting of acute kidney injury. Therefore, if the pH is greater than 6.9, administration of sodium bicarbonate may be inappropriate. However, because of the severity of the acidosis, the administration would be justified. Even though metformin is an extremely rare cause of lactic acidosis, particular care should be taken when using it for patients in whom renal blood flow has been altered, such as in those with acute kidney injury, sepsis, contrast studies, and acutely decompensated heart failure. More commonly, nucleoside reverse transcriptase inhibitors such as didanosine and stavudine, as well as isoniazid, cause lactic acidosis. Another type of lactic acidosis, D-lactic acidosis (the D-isomer of lactic acid), is rarely encountered in practice. This type of lactic acidosis is caused by intravenous (IV) infusions of products containing the excipient propylene glycol, such as IV lorazepam and IV diazepam, and typically occurs after high doses of continuous infusions.[5] Typical presentation is an increased osmolar gap, an increased anion gap, and renal failure.[6] Although propylene glycol can cause either lactic acidosis or D-lactic acidosis, the D-isomer is not detected in the routine assay; and thus, lactic acidosis may or may not be identified.[6] In these patients, determination of the osmolar gap is recommended, and its elevation would indicate the presence of D-lactic acid. However, the best option is testing D-lactic acid levels if the laboratory has such capability.

Case 2[7]

A 42-year-old man with human immunodeficiency virus (HIV) is admitted to the hospital with headache and fever. He is diagnosed with cryptococcal meningitis and initiated on amphotericin B and flucytosine. The patient exhibits a confused state of mind 1 week later, and the following laboratory values are drawn:

Electrolytes: Na^+ 152 mEq/L; K^+ 3.4 mEq/L; Cl^- 120 mEq/L; HCO_3^- 20 mEq/L; BUN 32 mg/dL; creatinine 1.4 mg/dL; glucose 112 mg/dL.

ABG: pH 7.30; pCO_2 36 mm Hg; pO_2 85 mm Hg.

Plasma osmolality 315 mOsm/kg (285 to 295 mOsm/kg); urine osmolality 150 mOsm/kg (500 to 800 mOsm/kg); urine Na^+ 25 mEq/L; urine K^+ 45 mEq/L; urine Cl^- 38 mEq/L; urine pH 6.2.

Normal anion gap metabolic acidosis is a result of either HCO_3^- loss or inadequate buffering.[1] The most common cause of HCO_3^- loss

is excessive diarrhea, but it can also be seen in proximal (type 2) renal tubular acidosis (RTA). Because stool has a basic pH, large-volume diarrhea can result in a loss of HCO_3^-, resulting in normal anion gap acidosis. In type 2 RTA, there is a disruption in the proximal reabsorption of HCO_3^-, resulting in lower serum HCO_3^- levels. Medications such as carbonic anhydrase inhibitors and ifosfamide are common iatrogenic causes of type 2 RTA.

Inadequate buffering in normal anion gap acidosis is a result of decreased distal H^+ secretion by luminal H^+-ATPase pumps in the collecting duct of the kidneys, defined as *distal RTA (type 1)*.[1] This decreased secretion of H^+ results in the inability to establish normally acidic urine and, therefore, results in a urine pH that is typically above 5.3. Another mechanism of type 1 RTA is secondary to increased permeability of the luminal membrane, resulting in back diffusion of secreted H^+ and distal secretion of K^+. Amphotericin B is an agent that inserts into the cell membranes and creates pores that decrease membrane permeability. The net result is H^+ retention and K^+ excretion, which results in normal anion gap acidosis and hypokalemia.[8]

In Case 2, the first step in the approach for evaluation of ABGs leads the reader to determine that that the patient has a metabolic process occurring with cryptococcal meningitis and that there is no reason for suspecting a respiratory problem. In addition to assessing the patient, evaluation of the pH reveals the presence of an acidosis. Evaluation of the respiratory component of the ABG shows that the pCO_2 is lower than normal, indicating a respiratory alkalosis is present. Furthermore, when assessing the metabolic component of the ABG, it is discovered the patient has a lower than normal HCO_3^-, indicating a metabolic acidosis is present. According to the approach described here, because of the presence of a metabolic acidosis, the next step is calculation of anion gap. When this is calculated, it is determined that a normal anion gap is present (12 mEq/L). Therefore, it is evident that the primary acid-base disturbance is a normal gap metabolic acidosis with respiratory alkalosis compensation. The urine electrolytes demonstrate K^+ loss and increased pH secondary to membrane permeability. In addition, the urinary anion gap is 32 (see Equation 4), indicating very low amounts of urinary H^+.[1] The cause of this disturbance is distal RTA secondary to amphotericin B nephrotoxicity.

Equation 4[1] Urinary anion gap
$= (\text{Urinary } Na^+ + \text{Urinary } K^+) - \text{Urinary } Cl^-$

METABOLIC ALKALOSIS

Case 3[9]

A 65-year-old man is admitted to the hospital for abdominal pain and diarrhea. He has a history of chronic constipation, for which he takes lactulose. An exploratory laparotomy revealed no obstruction 3 weeks before admission. He then developed pneumonia and received 5 days of gatifloxacin. He also developed large-volume, watery diarrhea without nausea or vomiting 5 days before admission. The following detail his laboratory results on admission:

Electrolytes: Na^+ 143 mEq/L; K^+ 3.3 mEq/L; Cl^- 102 mEq/L; HCO_3^- 33 mEq/L; BUN 19 mg/dL; creatinine 1 mg/dL; glucose 109 mg/dL.

ABG: pH 7.44; pCO_2 42 mm Hg; pO_2 53 mm Hg.

Clostridium difficile toxin: negative × 3

Metabolic alkalosis is characterized by a pH greater than 7.40 and a HCO_3^- greater than 28 mEq/L. Causes of metabolic alkalosis can be divided into gastrointestinal loss of H^+, renal loss of H^+, intracellular shift of H^+, or retention of HCO_3^-.[1] Gastrointestinal loss of H^+ usually is a result of vomiting and nasogastric (NG) suctioning or results from antacid use. Renal H^+ loss is associated with a number of conditions, including diseases of mineralocorticoid excess such as primary hyperaldosteronism or Cushing disease. The presence of hypokalemia in these conditions acts as a stimulus for H^+ secretion and HCO_3^- reabsorption. Diuretics also promote renal H^+ loss through distal secretion. This condition, referred to as *contraction alkalosis,* occurs secondary to increased secretion of aldosterone in response to hypovolemia, increased distal tubule flow, and hypokalemia that may result from diuretic use. Intracellular shift of H^+ is a result of hypokalemia caused by the transcellular shift of K^+ out of the cell and H^+ into the cell. In addition to diuretic use, vomiting can also lead to a condition of contraction alkalosis in which Na^+, Cl^-, and H_2O (water) are lost without HCO_3^-. Finally, retention of HCO_3^- as a result of excessive administration of sodium bicarbonate can also result in metabolic alkalosis.

Because the most common causes of metabolic alkalosis include vomiting, NG suction, and diuretics, the usual treatment involves administration of IV fluids containing sodium chloride (NaCl).[1] However, in

some cases patients may be resistant to administration of IV NaCl, usually because of edematous states or hypokalemia. In those patients, withholding conventional diuretics and perhaps administering a carbonic anhydrase inhibitor such as acetazolamide is recommended.

In Case 3, the stepwise approach indicates that the patient currently has a metabolic process occurring (large-volume diarrhea), as well as a pH that indicates alkalosis. The second step of the approach leads to the determination that the pCO_2 is slightly higher than normal, representing a respiratory acidosis. Furthermore, the HCO_3^- is higher than normal, demonstrating a metabolic alkalosis. The patient in this example has a primary metabolic alkalosis with respiratory acidosis compensation. It is puzzling, however, that this patient has large amounts of diarrhea and an alkalosis, a state in which observation of metabolic acidosis would normally be expected. Nevertheless, the etiology becomes clear on closer examination. The metabolic alkalosis present in this patient is most likely a result of hypokalemia combined with lactulose therapy. Lactulose creates an acidic stool, thereby trapping ammonium (NH_4^+) for excretion. Therefore, the patient is losing H^+ through diarrhea in a way that is analogous to vomiting or NG suctioning. The patient is given IV fluids; lactulose therapy is discontinued; and the metabolic alkalosis is resolved.

RESPIRATORY ACIDOSIS

Case 4[10]

An 89-year-old man with a history of heart failure and chronic kidney disease (baseline creatinine 1.6 mg/dL) is being treated in the hospital for a left femoral neck fracture. While in the hospital, he develops a urinary tract infection with *Pseudomonas aeruginosa* and begins experiencing decreased mental status, a temperature of 103°F, and a white blood cell count (WBC) of 41,000 cells/mm^3. At that time, he is on room air and his ABG shows pH 7.43, pCO_2 19 mm Hg, and pO_2 57 mm Hg. Therapy with gentamicin is started, and the patient's WBC begins to drop and his mental status improves. Days later he begins experiencing acute kidney injury secondary to gentamicin as evidenced by a serum creatinine of 4.5 mg/dL and a gentamicin trough of 6 mg/dL; thus, gentamicin is discontinued. His mental status begins deteriorating, and he starts going into respiratory failure. The ABG reveals pH 7.19, pCO_2 57 mm Hg, and pO_2 59 mm Hg. After 3 days of mechanical ventilation, the patient improves and is extubated.

Respiratory acidosis is characterized by a pH less than 7.40, and the condition results from retention of pCO_2; therefore, an elevated pCO_2 should be evident. Acutely, respiratory acidosis is most commonly associated with severe asthma exacerbations, pneumonia, pulmonary edema, and suppression of the respiratory center secondary to medications such as opioids, benzodiazepines, paralytics, and neuromuscular blockers.[1] Chronic respiratory acidosis is most commonly associated with chronic obstructive pulmonary disease and extreme obesity. Because the kidneys take days to compensate through secretion of H^+, acute respiratory acidosis must be treated by removal of the offending agent or by treatment of the underlying cause. Supplemental oxygenation may be required in severe cases.

In Case 4, the stepwise approach demonstrates that the patient has a pulmonary process occurring (respiratory failure), as well as a pH that is acidotic.[10] Evaluation of the pCO_2 from the time of respiratory failure indicates a respiratory acidosis. Although the HCO_3^- is not available for assessment, a change from the normal values of this measurement is not expected because metabolic compensation would take several days to occur. However, the patient is experiencing acute kidney injury secondary to an elevated gentamicin level; therefore, a metabolic acidosis may be present. Regardless, through assessment of the patient, it is evident that a pulmonary process is occurring; and it is clear that the patient has a primary respiratory acidosis with no evidence of metabolic compensation. The authors believe the acute respiratory failure is secondary to a rare adverse effect of gentamicin therapy known as *neuromuscular blockade*. After gentamicin is discontinued and mechanical ventilation is employed, the patient improves. Although it is rare, aminoglycosides have been associated with neuromuscular blockade, an adverse effect of which all clinicians should be cognizant. This condition is more commonly seen with gentamicin and neomycin than with tobramycin and amikacin.

RESPIRATORY ALKALOSIS AND MIXED ACID-BASE DISORDERS

Case 5[11]

A 58-year-old schizophrenic man is brought to the hospital because of strange behavior. He is completely disoriented and provides no history. The following laboratory values are collected:

Electrolytes: Na^+ 139 mEq/L; K^+ 4.7 mEq/L; Cl^- 90 mEq/L; HCO_3^- 14 mEq/L; BUN 18 mg/dL; creatinine 1 mg/dL; glucose 100 mg/dL.

ABG: pH 7.49; pCO_2 15 mm

Hg; pO_2 169 mm Hg (2 L nasal oxygen).

Respiratory alkalosis is characterized by a pH greater than 7.40 and hyperventilation resulting in a lower-than-normal pCO_2. This is commonly seen during states of hypoxia, such as in pneumonia, pulmonary emboli, heart failure, and severe anemia.[1] Other causes include psychogenic hyperventilation, pregnancy, hepatic failure, salicylate overdose, and cerebrovascular accidents. Treatment of respiratory alkalosis should be solely aimed at correcting the underlying cause.

Case 5 is complicated in the sense that it is a mixed acid-base disorder. If the stepwise approach is used, elevation in the patient's pH will be observed, indicating alkalosis. Unfortunately, assessing the patient is difficult because of his current mental status; therefore, laboratory values must be relied on exclusively. The pCO_2 is markedly decreased, indicating respiratory alkalosis. Furthermore, the HCO_3^- is also markedly decreased, indicating metabolic acidosis. After recognizing metabolic acidosis, the next step is calculation of the anion gap, which in this case is strikingly elevated at 35 mEq/L. After an increased anion gap is recognized, the next step is calculation of the delta gap (23 mEq/L), which is then added back to the serum HCO_3^- to determine what HCO_3^- would be in the absence of unmeasured anions. All this results in an HCO_3^- of 37 mEq/L. Therefore, this patient has a triple acid-base disorder: respiratory alkalosis, increased anion gap metabolic acidosis, and metabolic alkalosis. Upon further laboratory analysis, it is noted that his salicylate level is extremely elevated. The classic presentation of salicylate overdose involves respiratory alkalosis followed by an increased anion gap metabolic acidosis. A family member brings in an empty bottle of *Alka-Seltzer,* which contains aspirin and sodium bicarbonate, that was found near the patient's bedside. Thus, the patient is experiencing respiratory alkalosis and an increased anion gap acidosis secondary to aspirin overdose, and the metabolic alkalosis is secondary to excessive HCO_3^- ingestion.

CONCLUSION

Acid-base pathophysiology can be complicated and overwhelming for both novice and experienced clinicians. Recalling the 5 major disorders that can occur and using the stepwise approach proposed in this manuscript will help clinicians at all levels of training in assessment and development of treatment options for any acid-base disturbance encountered in practice.

TEST YOUR NEW SKILLS

Diagnoses for these cases can be found on page 818.

1. A 22-year-old man with no medical history is admitted after being "found down" at a party where he drank a fifth of whiskey in 20 minutes. On arrival to the emergency department (ED), he is neurologically unresponsive and has the following laboratory values: pH = 7.23; pCO_2 = 58 mm Hg; HCO_3^- = 24 mEq/L.
2. A 58-year-old woman has been hospitalized in the intensive care unit (ICU) for several weeks. Pneumonia and sepsis, requiring prolonged courses of antibiotics, have complicated her hospital stay. Over the past few days, she has begun spiking fevers, and she is having a lot of diarrhea. Her stool samples are positive for *C. difficile* toxin. Laboratory values include the following: Na^+ = 138 mEq/L; Cl^- = 115 mEq/L; HCO_3^- = 15 mEq/L; pH = 7.32; pCO_2= 30 mm Hg.
3. A 45-year-old woman in the ICU is intubated after a recent abdominal surgery. While in the operating room, she received more than 8 L of fluid and blood products, but she has been aggressively diuresed since that time. In the past 3 days she has generated 7 L of urine output, and her BUN and creatinine have increased to 40 mg/dL and 1.5 mg/dL, respectively. This morning her ABG shows the following: pH = 7.51; pCO_2 = 46 mm Hg; HCO_3^- = 35 mEq/L.
4. In the early morning hours, a 42-year old man is found down on the street; he is unresponsive. He is transported via ambulance to the ED. The patient is a John Doe with no known medical history. The following laboratory values are taken: Na^+ = 125; Cl^- = 79; K^+ = 7.5; HCO_3^- = 3; BUN = 45; creatinine = 3.2; glucose = 1,500; pH = 6.86; pCO_2 = 23. Blood has large ketones. Urine drug screen is positive for cocaine.
5. A 40-year-old man is admitted to the hospital with a 2-day history of persistent vomiting. The following laboratory values are taken: pH = 7.40; pCO_2 = 38 mm Hg; HCO_3^- = 26 mEq/L; Na^+ = 149 mEq/L; Cl^- = 100 mEq/L; BUN = 90 mg/dL; creatinine = 7.1 mg/dL.

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was found as dose dependent and reversible.[9] The patient in the case described here experienced that adverse effect, and it was reversible on discontinuation of colistin.

CONCLUSION

Intrathecal colistin is an effective treatment for MDR *P. aeruginosa* VPS infection. The main complication in the discussed case was arachnoiditis, which was reversible on discontinuation of therapy. Further studies are needed to clarify the role of intrathecal colistin for treating MDR, gram-negative CNS infections.

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ANSWERS TO ADDITIONAL CASES

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1. The patient has respiratory acidosis without metabolic compensation secondary to alcohol intoxication.
2. The patient has normal anion gap (8 mEq/L) metabolic acidosis with some respiratory alkalosis compensation secondary to diarrhea.
3. The patient has metabolic alkalosis with some respiratory acidosis compensation secondary to diuresis.
4. The patient has increased anion gap (43 mEq/L) metabolic acidosis with respiratory alkalosis compensation secondary to diabetic ketoacidosis (DKA). He also has metabolic alkalosis as determined by delta gap of 31 mEq/L, which when added back to HCO_3^-, results in HCO_3^- of 34 mEq/L. This is secondary to the volume contraction associated with DKA.
5. This is trickier. At first glance, it appears there is no acid-base disturbance because all the laboratory values are normal. However, assessment of the patient reveals that he has been vomiting and is experiencing acute kidney injury with possible uremia. Vomiting should produce metabolic alkalosis, and uremia should produce an increased anion gap acidosis. Calculation of the anion gap reveals that it is increased at 23 mEq/L. The delta gap is 11 and, when added back to the HCO_3^-, results in metabolic alkalosis with a HCO_3^- of 37 mEq/L. Thus, the patient has an increased anion gap metabolic acidosis and a metabolic alkalosis, which have canceled each other out to produce a normal pH.