Review Article

Respiratory Acid-Base Disorders: Respiratory Acidosis and Respiratory Alkalosis

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Abstract

Respiratory acid-base disorders are divided into respiratory acidosis (which can be acute or chronic), and respiratory alkalosis (which also can be acute or chronic). The diagnosis is made after obtaining arterial blood gases (ABGs). Respiratory acidosis is also known as primary hypercapnia and is due to an increase in carbon dioxide (CO_2) tension in bodily fluids. The metabolic compensation is an increase in serum bicarbonate (HCO_3^-), the increase is more pronounced in chronic respiratory acidosis. Oxygen administration (O_2) is critical in the management of respiratory acidosis. Respiratory alkalosis or primary hypocapnia is due to a decrease in CO_2 tension in bodily fluids. The metabolic compensation is a decrease in HCO_3^-, the decrease is more pronounced in chronic respiratory alkalosis. Rapid correction of respiratory alkalosis should be avoided, and the underlying etiology should be addressed.

Keywords: Respiratory Acidosis; Respiratory Alkalosis; Acid-Base Disorders; Acid-Base Physiology; Alkalemia; Acidemia

1. Respiratory Acidosis (Primary Hypercapnia)

1.1 Definition

Respiratory acidosis is acidemia (pH< 7.35) due to an increase in the CO_2 tension in bodily fluids. It is characterized by an increase in partial pressure of arterial CO_2 (P_aCO_2 > 45 mm Hg) due to alveolar

hypoventilation (primary hypercapnia) [1]. In respiratory acidosis the rate of CO_2 production is unmatched by the alveolar minute ventilation [2]. The lungs excrete about 15,000 mEq of hydrogen ion (H^+) daily as carbonic acid (H_2CO_3) resulting from lipid and carbohydrate metabolism. This is about 200 times the amount of renal acid excretion. Respiratory acidosis can be acute or chronic. In acute respiratory acidosis, HCO_3^- increases by 1 mEq/l for every 10 mm Hg increase in P_aCO_2. In chronic respiratory acidosis (>24 hours of duration), HCO_3^- increases by 4 mEq/l for every 10 mm Hg increase in P_aCO_2. The increase in HCO_3^- is called metabolic compensation. For the purpose of our discussion we consider a normal HCO_3^- level to be 24 mEq/l. In chronic respiratory acidosis this metabolic adaptation takes 3-5 days [3]. In simple acid-base disorders both P_aCO_2 and HCO_3^- move in the same direction (both are up in respiratory acidosis and metabolic alkalosis and both are down in respiratory alkalosis and metabolic acidosis) [4]. Movement of HCO_3^- and P_aCO_2 in the opposite direction is indicative of a mixed acid-base disorder.

For example, ABGs in a patient with chronic respiratory failure due to chronic obstructive pulmonary disease (COPD) show a pH of 7.35, P_aCO_2 of 70 mm Hg, and a HCO_3^- of 37 mEq/l. The diagnosis is chronic respiratory acidosis (simple acid-base disorder). HCO_3^- of 37 mEq/l is expected due to metabolic compensation for chronic respiratory acidosis. HCO_3^- will increase by 4 mEq/l for each 10 mm Hg increase in P_aCO_2. Since P_aCO_2 is 70 mm Hg, the expected increase in HCO_3^- is 3 x 4 = 12. Therefore, expected HCO_3^- 24 + 12 = 36 mEq/l which is very close to the actual value of 37 mEq/l.Now let us take the example of the same patient after a hospitalization with sepsis. ABGs show pH of 7.12, P_aCO_2 of 70 mm Hg, and HCO_3^- of 22 mEq/l. A pH of 7.12 is indicative of severe acidemia. In this patient P_aCO_2 and HCO_3^- moved in the opposite direction. This is indicative of a mixed acid-base disorder, namely, chronic respiratory acidosis due to COPD and metabolic acidosis due to sepsis [5]. Note that HCO_3^- is 22 mEq/l which is 14 mEq/l lower than the expected value of 36 mEq/l. This decline in HCO_3^- is the result of metabolic acidosis.

1.2 Causes

Respiratory acidosis is the result of depression of the respiratory center due to pulmonary or neuromuscular disorders. Respiratory acidosis can be acute or chronic (Table 1). Respiratory acidosis results when the rate of CO_2 generation exceeds the ability of the lungs to excrete it [3]. Examples of pulmonary disorders include, asthma, COPD, adult respiratory distress syndrome (ARDS), hypo-ventilation as in patients on mechanical ventilation, and permissive hypercapnia [6].

Examples of neuromuscular disorders are cerebrovascular accidents, sedatives, myasthenia gravis, and multiple sclerosis [7]. Mechanical ventilation is an important cause of respiratory acidosis as in pneumothorax, and displaced endotracheal tubes. Patients who are on mechanical ventilation due to acute hypoxemic respiratory failure precipitated by COVID-19 pneumonia often require high level of positive end-expiratory pressure (PEEP) [8]. PEEP in the presence of low cardiac output can cause respiratory acidosis due to an increase in alveolar dead space [9]. Permissive hypercapnia is occasionally used in mechanically ventilated patients to reduce barotrauma [10].

1.3 Diagnosis

The diagnosis of respiratory acidosis is made after

obtaining ABGs. In respiratory acidosis pH is < 7.35 and $PaCO_2$ > 45 mm Hg. An electrolyte panel including calcium, phosphate and magnesium is obtained. Kidney function tests and complete blood count (CBC) are also obtained. Knowledge of HCO_3^- allows calculation of metabolic compensation (Table 2) [1]. History and physical exam are critical. Medications can provide important clues to the diagnosis. Patients also require a chest X-ray. Further pulmonary testing such as pulmonary function studies and chest computed tomography (CT) is determined on case-by-case basis.

1.3.1 Example 1: A patient with terminal COPD presents with pH 7.32, $PaCO_2$ 83 mm Hg, and HCO_3^- 41 mEq/l. This patient has chronic respiratory acidosis due to COPD. For every 10 mm Hg increase in $PaCO_2$, HCO_3^- increase by 4 mEq. Therefore, for a $PaCO_2$ of 83 mm Hg, the expected HCO_3^- is 24 + (4 x 4) = 40 mEq/l. This is close to the HCO_3^- value on the chemistry profile. This indicates that the patient has a simple acid-base disorder (chronic respiratory acidosis).

1.3.2 Example 2: A patient with myasthenia gravis crisis is on mechanical ventilation. His recent history is significant for nausea and vomiting. His medication regimen includes furosemide. Initial ABGs: pH 7.33, $PaCO_2$ 68 mm Hg, HCO_3^- 35 mEq/l. This patient has acute respiratory acidosis due to myasthenia gravis crisis. The expected metabolic compensation should result in HCO_3^- of 27 mEq/l (with a maximal response of 30 mEq/l). HCO_3^- of 35 is indicative of concomitant metabolic alkalosis due to vomiting and the use of diuretics. Therefore, the patient has a mixed acid-base disorder, namely, acute respiratory acidosis and metabolic alkalosis.

Depression of the central nervous system: infections such as encephalitis, cerebrovascular accidents, general anesthesia, alcohol, sedatives overdose, head trauma, cerebral edema
Pulmonary disorders: COPD, asthma, laryngospasm, angioedema, atelectasis, pneumothorax, ARDS, pulmonary edema, pulmonary embolism, pulmonary fibrosis
Neuromuscular: myasthenia gravis, multiple sclerosis, muscular dystrophies, Guillain-Barr*é* syndrome, tetanus, status epilepticus, amyotrophic lateral sclerosis, poliomyelitis, toxins and medications such as succinylcholine and organophosphate.
Muscular: hypokalemia, hyperkalemia, hypophosphatemia
Mechanical ventilation: permissive hypercapnia and hypoventilation
Miscellaneous: Obesity-hypoventilation syndrome, kyphoscoliosis

Table 1: Causes of Respiratory Acidosis.

Disorder	Mechanism	pH	Compensation	Compensation limits
Metabolic acidosis	HCO_3^- ↓	↓	$P_aCO_2 = (1.5 \times HCO_3^-) + 8 \pm 2$ $P_aCO_2 = 15 + (HCO_3^-)$ P_aCO_2 = last 2 digits of pH Decrease in P_aCO_2 = 1.2 x decrease in (HCO_3^-)	P_aCO_2 = 10 mm Hg

Metabolic alkalosis	HCO_3^- ↑	↑	$P_aCO_2 = 40 + 0.6 (HCO_3^- - 24)$	$P_aCO_2 = 55$ mm Hg
Respiratory acidosis	P_aCO_2 ↑	↓	**Acute**: for every 10 mm Hg increase in P_aCO_2, there is 1 mEq/l increase in HCO_3^- **Chronic**: for every 10 mm Hg increase in P_aCO_2, there is 4 mEq/l increase in HCO_3^-	**Acute:** HCO_3^- = 30 mEq/l **Chronic:** HCO_3^-= 45 mEq/l
Respiratory alkalosis	P_aCO_2 ↓	↑	**Acute**: for every 10 mm Hg decrease in P_aCO_2, there is 2 mEq/l decrease in HCO_3^- **Chronic**: for every 10 mm Hg decrease in P_aCO_2, there is 5 mEq/l decrease in HCO_3^-	**Acute:** HCO_3^- = 18 mEq/l **Chronic:** HCO_3^- = 12 mEq/l

Table 2: Compensation for Simple Acid-Base Disorders.

1.4 Clinical Manifestations

The features of respiratory acidosis are a function of its severity and rapidity of onset. Acute respiratory acidosis can cause dyspnea, confusion, psychosis, headache, irritability and anxiety. Seizures are seen in severe cases. Chronic respiratory acidosis is associated with tremors, gait disturbances, somnolence and memory loss [7]. Hypercapnia is usually associated with hypoxemia. Hypercapnic encephalopathy is due to progressive CO_2 narcosis which results in coma [3]. High CO_2 leads to vasodilation of cerebral vessels with subsequent increase in intracranial pressure [11]. In severe cases papilledema can be seen on fundoscopic examination. Patients with chronic hypercapnia can have sodium (Na^+) and water retention especially if they have cor pulmonale. Severe hypercapnia can cause cardiac arrhythmias, low cardiac output and hypotension [6].

1.5 Treatment

The mainstay of treatment is addressing the underlying cause of respiratory acidosis. It is critical to know that respiratory acidosis is associated with hypoxemia and requires O_2 administration [3]. Acute and severe respiratory acidosis requires immediate action because it can be life-threatening. Some patients require endotracheal intubation and mechanical ventilation to correct acidemia and hypoxemia. Hypercapnia in patients with COPD should not be corrected aggressively. O_2 administration is done cautiously to avoid worsening hypercapnia resulting from depression of respiratory drive. Rapid and aggressive correction may lead to seizures, cardiac arrhythmia and decreased cerebral perfusion. Some patients develop hypercapnic coma. A reasonable goal is lowering P_aCO_2 to baseline level. Some critically ill patients have mixed metabolic acidosis and respiratory acidosis and may need sodium bicarbonate ($NaHCO_3$) infusion [1]. Alkali treatment in this setting remains an issue of controversy [12]. The goal is never to normalize pH and HCO_3^-, rather to reach a reasonable pH target of about 7.25. Low tidal volume ventilation is utilized [13]. Alkalemia causes respiratory depression via peripheral and central chemoreceptors. Frequent monitoring of ABGs and electrolytes in needed in this setting. In these patients, Potassium (K^+) should be repleted with potassium chloride (KCl), moreover, diuretics and corticosteroids should be decreased or discontinued [14].

Patients with chronic respiratory acidosis are treated with oxygen, bronchodilator, inhaled and systemic corticosteroids, and smoking cessation [1]. A pulmonary consultation is often required. To avoid post-hypercapnic metabolic alkalosis, patients should have adequate chloride (Cl^-) and K^+ to enable renal excretion of HCO_3^- (which has increased due to the metabolic compensation for respiratory acidosis). Some clinicians use acetazolamide in patients with post-hypercapnic metabolic alkalosis. Acetazolamide is bicarbonaturic and kaliuretic requiring frequent K^+ monitoring and aggressive replacement. It should only be used by clinicians familiar with it. Acetazolamide is dosed orally (PO) or intravenously (IV). The usual dose is 250-500 mg, two to three times daily. The Diabolo study was a double-blind, randomized trial conducted in 15 French intensive care units (ICUs) [15]. It enrolled 382 COPD patients on mechanical ventilation with either simple or mixed metabolic alkalosis. The active arm patients received a large dose of IV acetazolamide (500-1000 mg) twice daily. Acetazolamide did not change the duration of invasive mechanical ventilation via endotracheal intubation or tracheotomy, which was the primary study outcome. The small reduction in $HCO3^-$(0.8 mEq/l) in the acetazolamide group was statistically significant.

Development of metabolic alkalosis in patients with chronic respiratory acidosis leads to depression of respiratory drive. This makes weaning from mechanical ventilation more difficult. Banga and Khilnani retrospectively studied 84 COPD patients on mechanical ventilation. Post-hypercapnic metabolic alkalosis was seen in 20% and led to increased dependence on mechanical ventilation and longer stay in the intensive care unit [16]. Jeffrey et al. showed that arterial pH is important prognostically for survival. He studied 139 episodes of acute hypercapnic (type II) respiratory failure in 95 patients. Death occurred in 25% of the episodes with pH ≤ 7.25, as opposed to 7% of the episodes with pH >7.25 [17].

2. Respiratory Alkalosis (Primary Hypocapnia)

2.1 Definition

Respiratory alkalosis is alkalemia (pH >7.45) due to a decrease in arterial pressure of CO_2 (P_aCO_2 <35 mm Hg). It is the result of alveolar hyperventilation relative to CO_2 production (primary hypocapnia) [18]. Respiratory alkalosis can be acute or chronic. In acute respiratory alkalosis, HCO_3^- decreases by 2 mEq/l for every 10 mm Hg decrease in P_aCO_2. In chronic respiratory alkalosis (>24 hours of duration), HCO_3^- decreases by 5 mEq/l for every 10 mm Hg decrease in P_aCO_2. The decrease in HCO_3^- is called metabolic compensation. In chronic respiratory alkalosis, metabolic adaptation takes 2-3 days [2].

Metabolic compensation is efficient in chronic respiratory alkalosis and can result in normal arterial pH in contrast to other simple acid-base disorders. As above, in simple acid-base disorders both P_aCO_2 and HCO_3^- move in the same direction. For example, a patient with pulmonary fibrosis has on ABGs a pH of 7.47, P_aCO_2 of 24 mm Hg, and a HCO_3^- of 16 mEq/l. The diagnosis is chronic respiratory alkalosis (simple acid-base disorder). HCO_3^- of 16 mEq/l is expected due to metabolic compensation for chronic respiratory alkalosis. HCO_3^- will decrease by 5 mEq/l for each 10 mm Hg decrease in P_aCO_2. Since P_aCO_2 is 24 mm Hg, the expected decrease in HCO_3^- is 5 x 1.5 ≅ 8. Expected HCO_3^- is 24 - 8 = 16 mEq/l.

Now let us take the example of a patient hospitalized with pulmonary edema who was aggressively

receiving loop diuretics. ABGs show pH of 7.61, P_aCO_2 of 30 mm Hg, and HCO_3^- of 29 mEq/l. A pH of 7.61 is indicative of severe alkalemia. In this patient P_aCO_2 and HCO_3^- moved in the opposite direction. This is indicative of a mixed acid-base disorder, namely, acute respiratory alkalosis due to pulmonary edema and metabolic alkalosis due to aggressive diuresis. Note that HCO_3^- is 29 mEq/l which is 7 mEq/l higher than the expected value of 22 mEq/l. This rise in HCO_3^- is the result of metabolic alkalosis. Respiratory alkalosis is the most common acid-base disorder [19]. It is seen in the course of normal pregnancy, in exercise, and in people residing at high altitudes. It is also common in critically ill patients.

Hodgkin et al. studied 13,430 ABGs drawn from hospitalized patients [20]. The most common acid-base disorder was metabolic alkalosis (51%). Respiratory alkalosis was found in 29%, while respiratory acidosis was diagnosed in 27%. , Metabolic acidosis was the least common (12%). Some patients had mixed acid-base disorders, which explains why the reported incidence exceeds 100%. Alkalemia whether due to metabolic or respiratory alkalosis is associated with increased morbidity and mortality in surgical and medical patients. Anderson et al. conducted a prospective study in 409 medical and surgical patients. Mortality in patients with pH >7.60 was 48.5% [21].

2.2 Causes

Respiratory alkalosis is primary hypocapnia resulting from hyperventilation due to increased respiratory drive. The major causes of respiratory alkalosis are hypoxemia, central nervous system (CNS) stimulation, pulmonary disorders, in addition to medications and hormones (Table 3) [18]. Hypoxemia (partial pressure of arterial oxygen [P_aO_2] <60 mm Hg) leads to hyperventilation. Respiratory alkalosis is common in patients on mechanical ventilation. Examples of hypoxemia induced respiratory alkalosis include cardiogenic shock, hypotension, severe anemia and laryngospasm [22]. Hyperventilation due to CNS stimulation is seen in pain, fever, psychosis, and brain tumors [1]. Many pulmonary disorders result in respiratory alkalosis such as asthma, pneumonia, pulmonary embolism, pulmonary fibrosis and pneumothorax [2]. Examples of respiratory alkalosis due to medications and hormones include progesterone (as in pregnancy), salicylate, nicotine and xanthines [22]. Salicylate is the most common cause of medications induced hypocapnia. Respiratory alkalosis is seen in liver failure, sepsis and excessive heat exposure. Pseudorespiratory alkalosis is seen in some critically patients such as those in cardiogenic shock who are still maintaining adequate alveolar ventilation [23]. $PaCO_2$ in these patients is normal or low, while removal of CO_2 from body fluids is inadequate (tissue hypercapnia or respiratory acidosis). This may manifest with venous acidemia due to mixed metabolic acidosis and tissue respiratory acidosis, and mildly acidic or alkaline arterial pH [24]. Obtaining a mixed venous blood is helpful in making the diagnosis. Early in the course of acute asthma, respiratory alkalosis is common. If untreated, severe asthma will cause respiratory acidosis [6].

CNS stimulation: fever, pain, anxiety, psychosis, trauma, meningitis
Pulmonary disorders: asthma, ARDS, pulmonary edema, pulmonary fibrosis, pulmonary embolism, pneumothorax, flail chest
Hypoxemia: high altitude, severe anemia, hypotension, cardiogenic shock
Medications and hormones: salicylate, nicotine, progesterone, methylxanthines (aminophylline and theophylline)
Mechanical ventilation
Miscellaneous: exercise, sepsis, liver failure, heat exposure, pregnancy, recovery from metabolic acidosis

Table 3: Causes of Respiratory Alkalosis.

2.3 Diagnosis

As is the case in respiratory acidosis, history and physical exam are critical. Tachypnea is observed in some patients with respiratory alkalosis. The diagnosis of respiratory alkalosis is made after obtaining ABGs, otherwise low HCO_3^- may be erroneously attributed to metabolic acidosis [22]. In respiratory alkalosis pH is >7.45 and $PaCO_2$ < 35 mm Hg. CBC, urea, creatinine and an electrolyte panel including calcium, magnesium and phosphate are needed. Respiratory alkalosis increases the protein bound portion of calcium, thereby, reducing ionized calcium [25]. Respiratory alkalosis shifts Na^+, K^+ and phosphate intracellularly [11, 26]. Patients usually have hypokalemia and hyperchloremia. Knowledge of HCO_3^- allows calculation of metabolic compensation (Table 2). Other diagnostic tests are ordered depending on the underlying condition.

2.3.1 Example 1: A patient presents to the emergency department (ED) with a panic attack. His symptoms included shortness of breath, palpitations, chest pain, diaphoresis and facial numbness. ABGs revealed pH 7.53, $PaCO_2$ 25 mm Hg, and HCO_3^- 20 mEq/l. This patient has acute respiratory alkalosis due to his panic attack. For every 10 mm Hg decrease in $PaCO_2$, HCO_3^- decrease by 2 mEq. Therefore, for a $PaCO_2$ of 25 mm Hg, the expected HCO_3^- is 24 - (1.5 x 2) = 21 mEq/l. This is close to the HCO_3^- value on the chemistry profile. This indicates that the patient has a simple acid-base disorder (respiratory alkalosis).

2.3.2 Example 2: A patient with a known history of major depressive disorder presents to the ED with salicylate overdose. Her symptoms are significant for nausea, vomiting, abdominal pain and tinnitus. While in the ED she became increasingly confused. Her speech became slurred and she started to have visual hallucinations. Initial ABGs: pH 7.50, $PaCO_2$ 20 mm Hg, HCO_3^- 15 mEq/l. This patient has acute respiratory alkalosis due to salicylate overdose. The expected metabolic compensation should result in HCO_3^- of 20 mEq/l (with a maximal response of 18 mEq/l).

HCO_3^- of 15 is indicative of concomitant metabolic acidosis which is common in salicylate toxicity. Therefore, the patient has a mixed acid-base disorder, namely, acute respiratory alkalosis and metabolic acidosis. The patient was hydrated with isotonic $NaHCO_3$ drip (D5 with 150 mEq $NaHCO_3$/l) to achieve urinary alkalinization. Her serum salicylate level came back at 92 mg/dl and she improved quickly with hemodialysis.

2.4 Clinical manifestations

Acute and rapid respiratory alkalosis can lead to confusion, lightheadedness, cramps, numbness of the extremities and around the mouth (circumoral numbness). Rarely patients develop seizures. Acute respiratory alkalosis results in reduction in cerebral blood flow due to cerebral vasocontraction. Alkalemia (whether due to metabolic alkalosis or respiratory alkalosis) shifts the oxygen-hemoglobin dissociation curve to the left (decreasing O_2 availability to the tissues) and inhibits respiratory drive [27]. Alkalemia also induces hypokalemia and hypocalcemia [25]. Acute respiratory alkalosis is associated with atrial and ventricular tachyarrhythmias in patients with cardiac ischemia [2].

2.5 Treatment

The cause of respiratory alkalosis should be addressed. Severe hypocapnia should never be corrected rapidly because rapid correction will cause vasodilation and possible reperfusion injury to the lung and the brain [18]. Patients with anxiety induced hyperventilation (hyperventilation syndrome) should be instructed to breathe in a paper bag to increase their $PaCO_2$ [22]. Patients who are hypoxemic require oxygen administration. Acetazolamide orally is helpful in high-altitude sickness; slower ascent is recommended for prevention. Patients on mechanical ventilation benefit from certain adjustments such as adding dead space, sedation, paralytic agents or changing the mode of ventilation. Reducing HCO_3^- is helpful and it can be accomplished by using isotonic saline, acetazolamide and rarely by performing hemodialysis utilizing a low HCO_3^- bath.

3. Clinical Vignettes

1. A 60-year-old man presents with acute kidney injury due to hepatorenal syndrome. Laboratory evaluation is as follows: Na^+ 130, K^+ 6.1, Cl^- 99, HCO_3^- 15, anion gap (AG)16 (all in mEq/l), arterial pH 7.13, P_aCO_2 50 mm Hg. What is the acid-base disorder?

Answer: This patient has a pH of 7.13 indicating acidemia. HCO_3^- is 15 and AG is 16 indicating anion-gap metabolic acidosis. Since his P_aCO_2 is elevated at 50 mm Hg, while the expected response is a low P_aCO_2 around 29 mm Hg, he has mixed high anion-gap metabolic acidosis and respiratory acidosis [3, 4].

2. A 55-year-old woman with chronic COPD and cor pulmonale requiring the use of both furosemide and metolazone, presents with the following laboratory values: Na^+ 137, K^+ 3.2, Cl^- 85, HCO_3^- 35, AG 17 (all in mEq/l), arterial pH 7.46, P_aCO_2 51 mm Hg. What is the acid-base disorder?

Answer: The patient has a pH of 7.46 indicating alkalemia. HCO_3^- is 35 indicating metabolic alkalosis due to diuretics. Note also the hypochloremia and hypokalemia. In compensated metabolic alkalosis expected P_aCO_2 is 47 mmHg. Since P_aCO_2 is 51 mm Hg, he has mixed acid base disorder, namely metabolic alkalosis and respiratory acidosis (due to chronic COPD) [27].

3. A 58-year-old woman with acute on chronic systolic congestive heart failure requiring the use of intravenous furosemide and chlorothiazide, presents with the following laboratory values: Na^+ 129, K^+ 3.3, Cl^- 79, HCO_3^- 40, AG 10 (all in mEq/l), arterial pH 7.65, P_aCO_2 38 mm Hg, P_aO_2 61 mm Hg. What is the acid-base disorder?

Answer: The patient has a pH of 7.65 indicating alkalemia. HCO_3^- is 40 indicating metabolic alkalosis due to diuretics. Note also the hypochloremia and hypokalemia. In compensated metabolic alkalosis expected P_aCO_2 is 50 mmHg. Since P_aCO_2 is 38 mm

Hg, she has mixed acid base disorder, namely metabolic alkalosis and respiratory alkalosis (due to hypoxemia) [23].

4. A 61-year-old woman has a known history of end stage renal disease on hemodialysis. She has been not been adherent to her dialysis schedule. Her last hemodialysis was one week ago. She presents with uremic symptoms including nausea, vomiting, anorexia and dyspnea. On exam she was tachypneic and had generalized edema. Chest radiograph showed increased vascular congestion. Upon presentation to the ED she had the following laboratory values: Na^+ 131, K^+ 4.1, Cl^- 81, HCO_3^- 26, AG 24 (all in mEq/l), arterial pH 7.41, P_aCO_2 42 mm Hg, P_aO_2 65 mm Hg. What is the acid-base disorder?

Answer: At first glance the values of HCO_3^-, arterial pH and P_aCO_2 appear unremarkable. This patient has missed dialysis treatments and is exhibiting uremic symptoms. She has an elevated AG of 24 mEq/l, indicative of high anion-gap metabolic acidosis [4]. Using the formula:

Δ AG/Δ HCO_3^- = (measured AG – 10) / (24 - measured HCO_3^-)

Δ AG/Δ HCO_3^- = (24 – 10) / (24 – 26) = 14/-2

Therefore HCO_3^- is significantly elevated (the expected value is around 10 mEq/l), due to concomitant metabolic alkalosis resulting from vomiting. The next step is to calculate the respiratory compensation:

Expected P_aCO_2 = (HCO_3^- x 1.5) + 8 ± 2

Expected P_aCO_2 = (26 x 1.5) + 8 ± 2 = 47 ± 2. In this patient P_aCO_2 is 42 mm Hg, which is indicative of respiratory alkalosis due to hypoxemia. This patient a has triple acid-base disorder, high anion-gap metabolic acidosis, metabolic alkalosis and respiratory alkalosis. The concomitant three acid-base disorders have resulted in a pH, P_aCO_2 and HCO_3^- in the normal range.

5. A 28-year-old man with a known history of generalized anxiety disorder, presents with chest pain, palpitations, diaphoresis, and hyperventilation. After a thorough evaluation in the ED he was diagnosed with a panic attack. The following laboratory values were obtained: Na^+ 139, K^+ 3.4, Cl^- 105, HCO_3^- 22, AG 12 (all in mEq/l), arterial pH 7.49, P_aCO_2 30 mm Hg, P_aO_2 98 mm Hg. What is the acid-base disorder?

Answer: The patient has a pH of 7.49 indicating alkalemia. P_aCO_2 is 30 mm Hg. Therefore he has acute respiratory alkalosis due to hyperventilation. Hypokalemia due to intracellular K^+ shift is expected. Expected HCO_3^- is 22 mEq/l. This is a simple acid-base disorder, compensated respiratory alkalosis.

4. Conclusions

- Respiratory acidosis or primary hypercapnia is acidemia (pH< 7.35) due to an increase in P_aCO_2 (> 45 mm Hg) due to alveolar hypoventilation (metabolic CO_2 production exceeds its removal by the lungs).
- Respiratory alkalosis or primary hypocapnia is alkalemia (pH>7.45) due to a decrease in P_aCO_2 (< 35 mm Hg) due to alveolar hyperventilation (CO_2 removal by the lungs exceeds its metabolic production).
- In respiratory acidosis the metabolic compensation is a rise in HCO_3^-, and in respiratory alkalosis the metabolic compensation is a decrease in HCO_3^-. The change in HCO_3^- is more pronounced in chronic respiratory acidosis and chronic respiratory alkalosis.

- Respiratory alkalosis is the most frequent acid-base disorders. It is encountered in physiologic states such as living in high altitudes and pregnancy. It is also very common in hospitalized patients.
- Respiratory acid-base disorders are diagnosed after obtaining ABGs. The main treatment is addressing the underlying etiology.

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