# Acid Base Disturbances (Made Easy)

Introduction:

It has been my experience that many clinicians read volumes about acid-base, and even understand most of the basic principles, yet struggle when asked to rapidly solve real clinical cases. Emergency physicians must be able to "interpret the numbers" rapidly and accurately. While managing a critically ill patient in a busy E.D., you utilize your history, exam and initial data (EKG, SMA-6, ABG) to generate a differential diagnosis, order appropriate tests, begin therapy and determine disposition. It is easy to get confused trying to understand the complex pathophysiology of metabolic and respiratory disorders. We will focus on the most important disturbances that occur clinically, and the basic differential diagnosis of these disturbances. Accurate interpretation is fun and will lead to better patient care!

# I. Clinical Definitions and Pearls

- A. Acidemia is a state in which the blood pH<7.38 Alkalemia is a state in which the blood pH>7.42
- B. Acidosis is a **process** which tends to produce an acidemia, while alkalosis is a **process** which tends to produce an alkalemia. One, two or three processes can occur simultaneously.
- C. Mechanisms of acidosis and alkalosis are either metabolic or respiratory
  - 1. Respiratory: alkalosis always has  $pCO_2 < 38$ , acidosis always has  $pCO_2 > 42$
  - 2. Metabolic: alkalosis always has [HCO<sub>3</sub>]>28, acidosis always has [HCO<sub>3</sub>]<24
  - 3. The acid-base status can generally be understood from analysis of the ABG, and SMA-6.
  - 4. The Anion gap  $[Na^+ (Cl^++HCO_3)]$  adds more detailed information about the **type** of metabolic acidosis. Normal is<14 mEq/L. Use the measured HCO<sub>3</sub> from the SMA-6.
- D. Primary processes that change pH from neutral are only partially compensated; therefore the primary acute process (acidosis or alkalosis) is always evident from the acidotic (<7.38) or alkalotic (>7.42) pH. Compensation *never* reaches total correction, nor can you overcompensate. Chronic respiratory alkalosis is the only primary disorder where compensation can approach a normal pH.
- E. The respiratory system provides compensation for primary metabolic processes and the response occurs nearly immediately. A patient with a metabolic alkalosis cannot hypoventilate beyond a pCO<sub>2</sub> of 55-60 mmHg without essentially a respiratory arrest. On the other hand, a patient cannot hyperventilate beyond a pCO<sub>2</sub> of 12-14 in response to a metabolic acidosis. The kidneys provide compensation for primary respiratory processes by adjusting HCO<sub>3</sub> reabsorption in the proximal tubules. The renal (metabolic) response is not immediate. Compensation lags by 6-12 hours and may require 24-48 hours to reach a steady state.

# II. Interpretation of Acid-Base Status

Don't panic Keep it simple! Look at the ABG! Calculate and understand the anion gap

## Try to recognize patterns, de-emphasize memorization of equations and tables!

- A. Is the pH acidic or alkalotic? The answer to this question <u>usually</u> identifies the **primary** disturbance (acidosis or alkalosis).
- B. Does  $pCO_2$  suggest hyperventilation ( $pCO_2 < 38$ ) or hypoventilation ( $pCO_2 > 42$ )?
- C. Remember: the  $HCO_3$  in the ABG is calculated from the pH and  $pCO_2$ . This calculated value doesn't really help to interpret the disturbance. The **measured** bicarbonate in the chem-6 is more accurate and enhances the validity of the ABG.
- D. Put together the information from pH and  $pCO_2$  and measured bicarbonate.

# Acidosis (pH<7.38) AND

- 1.  $pCO_2 < 38$ : the primary process is an acidosis (pH acidic) with a respiratory alkalosis (hyperventilation) as partial compensation. Thus the primary acidosis must be a metabolic acidosis. The lingo would call this a "metabolic acidosis with respiratory compensation". Bicarbonate will be low.
- 2. pCO<sub>2</sub> 38-42: primary acidosis without respiratory compensation, thus a pure metabolic acidosis (this rarely occurs)
- 3. pCO<sub>2</sub>>42: primary respiratory acidosis.

Here you need the bicarbonate to tell you whether the patient has, in addition, a primary metabolic acidosis (HCO<sub>3</sub><24), or has compensated for the respiratory acidosis (HCO<sub>3</sub>>28).

## Alkalosis (pH>7.42) AND

1.  $pCO_2 < 38$ : primary respiratory alkalosis.

Here you need the bicarbonate to tell you whether the patient has a superimposed primary metabolic alkalosis (i.e.  $HCO_3>28$ ) as well. This rarely occurs except iatrogenically in mechanically ventilated patients.

- 2. pCO<sub>2</sub> 38-42: a primary alkalosis without respiratory compensation, thus a primary metabolic alkalosis, uncompensated.
- 3.  $pCO_2>42$ : primary metabolic alkalosis with respiratory compensation.

Easy, huh . . . . . . . . . . .

# III. Compensation

There are also some formulas that allow you to calculate whether the compensation that occurs is an "appropriate" response to the primary process or whether this "compensation" actually reflects the presence of a **second** primary process. Be familiar with these simple formulas, and know when to apply them. These four formulas are my personal favorites.

- 1. <u>Acute Metabolic Acidosis</u>: Winter's Formula is used to calculate whether the **respiratory compensation** (hyperventilation) to a metabolic acidosis is appropriate. In a metabolic acidosis (gap or non-gap),  $pCO_2 = 1.5$  [HCO<sub>3</sub>]+8 ± 2. If the patient's  $pCO_2$  is higher, the patient has a superimposed **primary** respiratory acidosis (hypoventilation). If the  $pCO_2$  is below this range, the patient has a superimposed **primary** respiratory alkalosis (hyperventilation).
- <u>Acute Metabolic Alkalosis</u>: The "appropriate" respiratory compensation for a metabolic alkalosis should be an increase in pCO<sub>2</sub> of 0.6 for each 1 mEq/L increase in HCO<sub>3</sub> A greater increase in pCO<sub>2</sub> implies a superimposed **primary** respiratory acidosis, a smaller increase in pCO<sub>2</sub> implies a superimposed **primary** respiratory alkalosis (hyperventilation). Note: pCO<sub>2</sub> should never rise above 55-60 mHg as compensation for a metabolic alkalosis.
- 3. <u>Chronic Respiratory Acidosis</u>: HCO<sub>3</sub> should <u>increase</u> by 3.5 for every 10mm Hg increase in pCO<sub>2</sub>. A greater increase in bicarbonate implies a superimposed **primary** metabolic alkalosis, a smaller increase in bicarbonate implies either a superimposed **primary** metabolic acidosis or an acute respiratory acidosis and metabolic compensation has not had time to occur.
- 4. <u>Chronic Respiratory Alkalosis</u>: bicarbonate should <u>decrease</u> by 5 for every 10 mm Hg decrease in pCO<sub>2</sub>. A greater decrease in bicarbonate implies a superimposed **primary** metabolic acidosis, a smaller decrease in bicarbonate implies a superimposed **primary** metabolic alkalosis or compensation which is not complete, (i.e. an acute respiratory alkalosis).

# IV. Diagnosis of Specific Causes of Primary Acid-Base Disturbances

## A. Metabolic Acidosis: The Anion Gap

A thorough knowledge of the anion gap allows the clinician to recognize subtle findings "hidden" in the SMA-6. The basic principle of electroneutrality dictates the total mEq/L of cations must equal the total mEq/L of anions. Since serum sodium accounts for 90% of all cations and chloride plus bicarbonate 85% of all anions, the difference between these in mEq/L represents the anion gap (AG).

$$AG = Na - (Cl + HCO_3)$$

Unmeasured cations include potassium, calcium, magnesium while unmeasured anions include protein, sulfate, phosphate, etc. The "normal" AG is the range of 8-14 mEq/liter. The finding of an elevated AG is synonymous with the presence of a metabolic acidosis. The presence of an "unmeasured anion" lowers the serum bicarbonate via buffering, hence elevating the anion gap.

While the **identification** of a primary metabolic acidosis is made by examining the ABG, the **diagnosis** depends on the anion gap and the clinical situation. It is useful for diagnostic purposes to divide metabolic acidoses into **increased anion gap** metabolic acidoses and **non-anion gap** metabolic acidoses. An increase in anion gap implies an increase in acid production or a decrease in acid clearance (by the kidney). In all metabolic acidoses, by definition, bicarbonate is low; if the anion gap is normal, [Cl] must be high. Thus another name for "non-anion gap metabolic acidosis" is "hyperchloremic metabolic acidosis". These processes are generated by the loss of bicarbonate (via the kidney or GI tract) replaced physiologically with chloride.

#### **Causes of Anion Gap Metabolic Acidoses**

Ketoacidosis

Diabetic, Alcoholic, Starvation

Renal failure

Lactic Acidosis (shock in most cases)

Type A: Shock States, CHF, Hypoxia, Anemia, CO poisoning

Type B: Ischemic bowel, DM, Uremia, Hepatic Failure, Seizures, Leukemia, Drugs, Inborn errors

Exogenous Toxins Leading to Lactic Acidosis

Cyanide, CO, Ibuprofen, INH, Iron, Strychnine, Toluene

Exogenous Toxins Metabolized to Acids

ASA, Methanol, Ethylene Glycol, Paraldehyde

Or use this Pneumonic:

#### **MUDPILES**:

Methanol Uremia Diabetic ketoacidosis Paraldehyde, phenformin Iron, isoniazid, inhalants Lactic acidosis Ethylene glycol, ethanol (alcoholic ketoacidosis) Salicylates, solvents, starvation ketosis

# Look for an osmolar gap in patients with an anion gap metabolic acidosis, and the etiology is unknown. It occurs in these two intoxications:

#### 1. Methanol

# 2. Ethylene glycol

- Calculate Osmolar gap:
  - Step 1: osm = 2 (Na+) + (gluc/18) + (BUN/2.8) + (BAL/5) norm = 285-295 mOsm/LStep 2: Measured - calculated should be < 10-15
- <u>Anion Gap Without Acidosis (rare)</u>
   citrate, lactate, acetate, high dose PCN or Carbenicillin, dehydration, severe respiratory or metabolic alkalosis may widen AG
- Ketosis without Acidosis ketosis & increased osmolar gap without acidosis or anion gap = isopropyl alcohol ingestion

# Causes of Non Anion Gap (Hyperchloremic) Metabolic Acidoses

Michael Chansky, MD, FACEP Acid Base Disorders GI loss of HCO3- (normal urine anion gap or UAG) Diarrhea (especially children) Small bowel/pancreatic fistula Ureteral diversion Ileal loop (obstructed or too long) Anion exchange resins (cholestyramine) Ingestion of CaCl<sub>2</sub>, MgCl<sub>2</sub> Renal loss of HCO3- (Wide UAG) RTA Early renal failure Carbonic anhydrase inhibitors (eg. Diamox) Tubulointerstitial renal disease Hypoaldosteronism - deficiency or drug inhibition Hyperparathyroidism Addition of HCl acid Ammonium Cl, Arginine HCl, Lysine HCl Post Treatment of DKA [replacing lost bicarbonate equivalents (ketones in urine) with Cl] Rapid NS Hydration (Dilutional Acidosis)

In hyperchloremic acidosis (normal anion gap) the urinary anion gap can be calculated = ([Na+] + [K+]) - [Cl-]. Normal range = 30 - 50 mEq/L. If the UAGap is normal it points to GI losses of bicarbonate and if elevated renal losses.

**Treatment** of metabolic acidosis requires treating the underlying cause. Bicarbonate is generally withheld until pH is very low (below 7.10 - 7.15). The dose of bicarbonate should not exceed 0.5 - 1 mEq/kg at a time with additional doses guided by further measurements of pH, pCO<sub>2</sub>, and HCO<sub>3</sub>, correction = 0.5 (wt in Kg) x (desired bicarbonate - measured bicarbonate) in mEq/L.

# General Rule: correct with 50% calculated bicarbonate deficit and recheck the serum level and pH to prevent over correction.

Possible complications of bicarbonate administration include:

alkalosis volume overload hypokalemia decreased ionized calcium paradoxical cerebral acidosis shift of oxygen dissociation curve to the left

**Low Anion Gap:** You may occasionally come across a patient with a very low anion gap. A "low" anion gap is defined as <6. Causes of a low anion gap include the addition of unmeasured cations, (paraproteins, calcium, magnesium, lithium) that are offset by measured anions, reduced concentration of unmeasured anions (dilution, hypoalbuminemia), systematic underestimation of serum sodium (hypernatremia, hyperviscosity) and systematic overestimation of chloride (bromism).

# B. Metabolic Alkalosis

Primary elevation of plasma bicarbonate concentration with a subsequent increase in pH:

a. Loss of acid or addition of alkali sufficient to generate met alkalosis

b. Enhanced renal reabsorption (or regeneration) of bicarbonate

# \* BOTH MUST BE PRESENT FOR A STATE OF METABOLIC ALKALOSIS TO EXIST \*

Most common causes are volume depletion (associated with excessive loss of K+) and loss of gastric secretions (loss of H+ and Cl) via vomiting or NG tube, and diuretic use. Volume depletion generates the alkalosis, the kidney maintains it! Volume depletion stimulates aldosterone, which promotes sodium uptake and potassium loss via the kidney. In chloride depleted patients, the sodium is reabsorbed with bicarbonate, which leads to an elevated bicarbonate level in a volume depleted patient. **Diagnosis** depends on the clinical situation and measurement of urinary chloride.

Saline Responsive (Urine Cl- < 10 mEq/L)	Saline-Resistant (Urine Cl- > 10 mEq/L)
GI: vomiting, NG suction, Cl- diarrhea	Mineralocorticoid excess
villous adenoma	- Primary aldosteronism
Diuretic therapy	- Secondary: CHF, Cirrhosis, Ascites,
Cystic Fibrosis	Malig HTN,
Posthypercapnia	ACTH excess (Cushing disease/syndrome,
Alkali syndrome	ectopic),Bartter's, licorice, renin-tumor,
	chewing tobacco,
	Liddle's, severe K+ depletion, congenital
	Adrenal Hyperplasia

Misc: refeeding alkalosis, non parathyroid hypercalcemia (IE. bone mets, massive blood or plasma substitute)

Treatment is volume, with KCl as indicated.

#### C. Respiratory Acidosis (primary hypoventilation)

Primary impairment is the rate of alveolar ventilation leading to an increase in the pCO2 with subsequent decrease in serum pH.

- a. Acute:
  - 1) CNS depression (ie. narcotic overdose)

# 2) Paralysis of respiratory muscles

Neuromuscular causes

- ingestion/O.D. of sedatives, tranquilizers, anticholinesterases, anesthetics
- cerebral, brainstem, or high spinal cord injury or infarct
- primary neuromuscular diseases: Guillain-Barre Syndrome, Myasthenia Gravis, ALS, Poliomyelitis, Botulism, Tetanus
- myopathy of respiratory muscles: Muscular Dystrophy, Hypokalemic myopathy, electrolyte imbalance (decreased PO<sub>4</sub>, Mg), familial periodic paralysis
- primary hypoventilation
- sleep apnea syndrome
- diaphragmatic paralysis

# 3) Airway obstruction

- Upper: laryngeal edema/spasm, tracheal edema/stenosis, obstructive sleep apnea
- Lower: mechanical, i.e.: foreign body, aspirated fluid, neoplasm, bronchospasm

# 4) Respiratory Failure

cardiac arrest, pneumonia, pulmonary edema, ARDS, restrictive lung disease, pulmonary embolism, pneumo/hemothorax, chest trauma, smoke inhalation, Iatrogenic (mechanical ventilation)

- b. Chronic:
  - 1) Chronic airway disease, i.e.: COPD, Emphysema
  - 2) Extreme kyphoscoliosis
  - 3) Extreme obesity (pickwickian syndrome)

**Treatment** of respiratory acidosis requires treatment of the underlying cause. If respiratory insufficiency is severe, mechanical ventilation will reverse the acidosis (don't correct **chronic** hypoventilation too rapidly). Bagging these patients aggressively post intubation can cause an acute severe respiratory alkalosis, carpal-pedal spasm and tetany due to a low ionized calcium.

# D. Respiratory Alkalosis (primary hyperventilation)

Hyperventilation (not necessarily tachypnea), reduces the arterial pCO2 and consequently increases the arterial pH.

Causes Include:

Early shock - (Respiratory Alkalosis is the earliest acid-base disorder of hypovolemic shock)
Early sepsis
Fear, anxiety
Pulmonary disease (CHF, asthma, pneumonia, pulmonary embolism)
CNS infection or CVA
Pregnancy
Liver disease
Hyperthyroidism
Salicylates (adults)

**Treatment:** treat the underlying problem.

# V. Mixed Acid Base Disturbances

In a mixed disturbance there is more than one primary process. Suspect a mixed disturbance when a simple disturbance with compensation does not explain the laboratory or clinical picture. The most common example in the ED setting is **primary metabolic acidosis with primary respiratory alkalosis** (e.g. pH 7.56, pCO<sub>2</sub> 15, HCO<sub>3</sub> 14, anion gap 20).

Causes:

CHF, pulmonary edema, (measuring p0<sub>2</sub> may help, should be low) Sepsis (early) Shock (early) Liver disease Salicylates

## VI. Triple Disturbances (advanced stuff)

Triple Disturbances are common in the E.D. Metabolic acidosis, alkalosis and respiratory alkalosis are seen in various clinical settings. SUSPECT a metabolic acidosis and alkalosis in a patient with a large anion gap and bicarbonate > 15. Use the "Delta Delta" formula to calculate the patient's bicarbonate equivalent. (Patient's anion gap-10 (normal gap) = Delta Delta. Add this number to the patient's bicarbonate to calculate the equivalent). This concept will be discussed during my practice case session next; so do not panic if you are confused.

## VII. Practical Approach to Cases

Approach cases in a calm, step-wise fashion. It is imperative that you are familiar with the differential diagnosis of all four primary acid base disturbances:

1. Metabolic Acidosis	3. Respiratory Acidosis
Gap Vs Non-Gap	Acute Vs Chronic
2. Metabolic Alkalosis	4. Respiratory Alkalosis
	Acute Vs Chronic

The available history/examination will always provide key clues to the underlying acid base disturbance. Because the most important process to pick up in the acute care setting is metabolic acidosis, you must be comfortable with the concept of the anion gap, and understand how to apply Winter's Formula (respiratory compensation for a metabolic acidosis).

Calculate the anion gap in *EVERY* SMA-6. If the patient has an anion gap, you have defined a metabolic acidosis. Next use Winter's Formula, to calculate what the pCO<sub>2</sub> should be for ideal respiratory compensation, pCO<sub>2</sub> = 1.5 (HCO<sub>3</sub>) +8  $\pm$ 2. If the patient's pCO<sub>2</sub> is lower than calculated, the patient has a respiratory alkalosis. If the pCO<sub>2</sub> is higher, the patient has a respiratory acidosis.

If a patient has an anion gap metabolic acidosis how can we possibly figure out if a metabolic alkalosis is also present? They frequently coexist. This is where you must apply the so-called "delta-delta". Let's walk through this.

A patient has an anion gap (AG) of 25 and measured bicarbonate of 22. The presence of an anion gap <u>and</u> a near normal bicarbonate is the first clue that a metabolic alkalosis is also present. Assume two things:

- 1. the normal gap is 10.
- 2. for every unit rise in the anion gap above 10, the patient's bicarbonate was lowered by one unit (via buffering).

Therefore, this patient's "delta-delta" is 25 (pt's AG) - 10 (normal AG) = 15. (pt's AG minus the normal anion gap = delta-delta)

According to assumption 2 this patient's bicarbonate was lowered 15 units by the production of 15 units of acid. Therefore, this patient's "bicarbonate equivalent" is 15 plus the measured bicarbonate (22) or 37. A serum bicarbonate of 37 clearly characterizes a metabolic alkalosis. You will need to practice this, and we will!

Let's move on.

If the patient does not have an anion gap, look for a low bicarbonate and high chloride, which defines a hyperchloremic non-anion gap metabolic acidosis. Use Winter's Formula to check for appropriate respiratory compensation.

If neither a gap or non-anion gap metabolic acidosis is present, then your patient can only have the following:

- 1. Metabolic Alkalosis (high HCO<sub>3</sub>, high pCO<sub>2</sub>, alkaline pH)  $\Delta$  PCO<sub>2</sub> from normal = pt's bicarbonate - 24 (normal HCO<sub>3</sub>) x 0.6
  - a) Metabolic Alkalosis and a Respiratory Acidosis or Respiratory Alkalosis as determined by the above formula.

2. Respiratory Acidosis (high pCO<sub>2</sub>, high HCO<sub>3</sub>, acid pH)

 $\Delta$  HCO3 = 3.5 mEq/L per 10 mmHg rise in CO<sub>2</sub>

3. Respiratory Alkalosis (low pCO<sub>2</sub>, low HCO<sub>3</sub>, alkaline pH)

 $\Delta HCO_3 = 5 \text{ mEq/L}$  for every 10 mm decrease in CO<sub>2</sub>

#### VIII. Example

A patient is wheeled in from a nursing home in shock and hypothermic.

Na+	=	143	pН	=	7.61
K+	=	3.9	pCO <sub>2</sub>	=	23
Cl-	=	98	$pO_2$	=	95
HCO <sub>3</sub>	=	22	HCO <sub>3</sub>	=	22
Glu	=	126			
BUN	=	9			

At first glance the patient's chem-6 looks relatively normal, with no acid base disturbance present. Luckily, an ABG was drawn because the patient looked clinically ill and it was apparent from the ABG that there was an acid-base disorder. A fast glance would lead you to believe this is a simple case of respiratory alkalosis.

1. pH > 7.42, therefore alkalotic.  $CO_2$  low.  $HCO_3$  low.

However, since you are now a seasoned expert in acid-base physiology you correctly calculate the anion gap.

2. AG = 143 - (22 + 98) = 23.

This number is > 14 and represents an anion gap metabolic acidosis. You now recall your brief differential diagnosis list and go back to the patient to get further history and physical exam information. The next step in your analysis is to determine the degree of respiratory compensation for this metabolic disorder via Winter's formula.

3. Winter's formula: 
$$pCO_2 = 1.5 (22) + 8 (+2)$$
  
 $pCO_2 = 41 (\pm 2)$ 

Since the patient's pCO2 is much less than the expected pCO2 (23) we confirm a concurrent respiratory alkalosis. As you recall from the lecture, in any patient with metabolic acidosis and a bicarbonate level close to normal you should suspect a mixed metabolic acidosis/alkalosis and calculate the "delta-delta".

A: 23 (pt's actual AG) - 10 (normal AG) = 13, thus this "HCO<sub>3</sub> equivalent" = 13

B: 13 + 22 (measured HCO<sub>3</sub>) = 35, which clearly represents a metabolic alkalosis

As you can see from these simple calculations, this patient has a triple disorder, which was dangerously close to going unnoticed.

After a little practice, this *REALLY* will become easy. Remember: real patients do not follow formulas, and may have numbers that seem a little "off". Use common sense and do not label a patient with a primary acidosis because the anion gap is 15. **PRACTICE CASES!** 

## Acid Base Disturbances (Addendum)

# **Case Studies:**

1. A 25-year-old schizophrenic is brought to the Emergency Department comatose after ingestion of radiator fluid.

Na+	=	135	рН =	6.96
<b>K</b> +	=	8.4	$pCO_2 =$	14
Cl-	=	100	<b>pO</b> <sub>2</sub> =	<b>98</b>
HCO <sub>3</sub>	=	4	$HCO_3 =$	4
Glu	=	158		
BUN	=	21		

2. A hemodialysis patient presents after 18 hours of vomiting.

Na+	=	140	pН	=	7.40
K+	=	4.8	pCO <sub>2</sub>	=	39
Cl-	=	91	pO <sub>2</sub>	=	97
HCO <sub>3</sub>	=	22	HCO <sub>3</sub>	=	22
Glu	=	181			
BUN	=	46			

**3.** A 40-year-old woman with gallstones presents with abdominal pain, vomiting and hyperamylasemia.

Na+	=	132	рН =	7.56
<b>K</b> +	=	2.9	$pCO_2 =$	<b>48</b>
Cl-	=	86	$\mathbf{pO}_2 =$	85
HCO <sub>3</sub>	=	38	$HCO_3 =$	38
Glu	=	81		
BUN	=	26		

4. A NIDDM patient is wheeled into the Emergency Department appearing ill and lightheaded.

Na+	=	143	pH =	7.50
<b>K</b> +	=	3.6	<b>pCO</b> <sub>2</sub> =	40
Cl-	=	85	$\mathbf{pO}_2 =$	70
HCO <sub>3</sub>	=	30	$HCO_3 =$	30
Glu	=	474		
BUN	=	43		

5. A 21-year-old female presents with dyspnea, polyuria and polydipsia.

Na+	=	125	pН	=	7.19
K+	=	3.5	pCO <sub>2</sub>	=	20
Cl-	=	91	pO <sub>2</sub>	=	105
HCO <sub>3</sub>	=	8	HCO <sub>3</sub>	=	8
Glu	=	612			
BUN	=	13			
Next N	Iorning	:		VBG:	
	=	143	рН	=	7.29
	0		рН pCO <sub>2</sub>	=	7.29 31
Na+	=	143	+	=	
Na+ K+	= = =	143 3.8	pCO <sub>2</sub>	= = =	31
Na+ K+ Cl-	= = =	143 3.8 119	pCO <sub>2</sub> pO <sub>2</sub>	= = =	31 48
Na+ K+ Cl- HCO <sub>3</sub>	= = = =	143 3.8 119 12	pCO <sub>2</sub> pO <sub>2</sub>	= = =	31 48

6. A chronic alcoholic is brought to the Emergency Department vomiting and complaining of abdominal pain.

Na+	=	137	pН	=	7.40
<b>K</b> +	=	3.8	pCO <sub>2</sub>	=	41
Cl-	=	90	pO <sub>2</sub>	=	85
HCO <sub>3</sub>	=	22	HCO <sub>3</sub>	=	22
Glu	=	138			
BUN	=	20			

# 7. A health care professional presents with dizziness.

Na+	=	123	рН	=	7.55
K+	=	3.1	pCO <sub>2</sub>	=	50
Cl-	=	67	pO <sub>2</sub>	=	80
HCO <sub>3</sub>	=	42	HCO <sub>3</sub>	=	43
Glu	=	125			
BUN	=	25			

8. An elderly woman with severe arthritis is found in her apartment lethargic and confused.

Na+	=	137	pН	=	7.60
K+	=	3.6	pCO <sub>2</sub>	=	25
Cl-	=	95	pO <sub>2</sub>	=	80
HCO <sub>3</sub>	=	20	HCO <sub>3</sub>	=	20
Glu	=	126			
BUN	=	9			

9. A 34-year-old with severe asthma has been dyspneic for 4 days.

Na+	=	132	pH =	7.55
K+	=	3.6	$\mathbf{p}\mathbf{CO}_2 =$	28
Cl-	=	105	$\mathbf{pO}_2 =$	69
HCO <sub>3</sub>	=	18	$HCO_3 =$	18
Glu	=	110		
BUN	=	15		

10. A 58-year-old smoker is brought to the ED severely dyspneic.

Na+	=	132	pH =	7.20
<b>K</b> +	=	3.5	$pCO_2 =$	70
Cl-	=	92	$pO_2 =$	50
HCO <sub>3</sub>	=	30	$HCO_3 =$	30
Glu	=	110		
BUN	=	12		

11. A 25-year-old man is brought to the ED comatose, by paramedics. There was no response in the field to  $D_{50}$  and Narcan. Initial labs reveal:

Na+	=	141	pН	=	7.40
<b>K</b> +	=	4.0	pCO <sub>2</sub>	=	40
Cl-	=	103	pO <sub>2</sub>	=	84
HCO <sub>3</sub>	=	25	HCO <sub>3</sub>	=	25
Glu	=	90			
BUN	=	14			

Ethanol: negative Urine Dip: negative glucose, large ketones Measured Osmolarity of 338

12. A 30-year-old man is found down at a bus station. Paramedics respond, draw blood, start on IV and transport. D<sub>50</sub> and Narcan given in route leads to considerable improvement in the patient's mental status. Explain the lab results from the field blood.

Na+	=	139	ABG <u>upon arr</u>	ival to the ED
K+	=	3.1		
Cl-	=	102	pH =	7.43
HCO <sub>3</sub>	=	14	<b>pCO</b> <sub>2</sub> =	38
Glu	=	110	$pO_2 =$	89
BUN	=	12	$HCO_3 =$	23

13. A 45-year-old woman is S/P thyroid surgery 2 weeks ago. She presents with painful spasms of her legs and arms. She has a positive Chvostek's sign on exam.

Na+	=	142	
K+	=	4.0	Why is her Anion Gap 18?
Cl-	=	100	
HCO <sub>3</sub>	=	24	
Glu	=	100	
BUN	=	10	

14. A teenage girl presents with severe weakness over the past 2-3 days. She denies drug use, vomiting or alcohol. Interpret the numbers:

Na+	=	138	pH =	7.28
K+	=	1.8	$\mathbf{p}CO_2 =$	30
Cl-	=	115	$\mathbf{pO}_2 =$	100
HCO <sub>3</sub>	=	13	$HCO_3 =$	13
Glu	=	104		
BUN	=	12		

15. A 51-year-old with IDDM and alcohol abuse presents with 3 days of N/V. She is uncooperative.

6

Case Studies: Many of these are real ED cases I have seen in recent years.

- 1. This patient is obviously very ill and requires your immediate attention to the ABC's. A quick glance at the ABG, which invariably comes back quickly reveals a profound acidemia. This must be a metabolic acidosis, as the bicarb and pCO2 are low. You think of your simple DDx (lactate, ketones, uremia and ingestions) and move on the SMA-6. This reveals an anion gap of 31, bicarb of 4, and severe life threatening hyperkalemia. Knowing this patient has a severe metabolic acidosis, you quickly calculate what the pCO2 should be for this bicarb, using Winter's formula. pCO2 = 1.5 (HCO3) + 8 ± 2. pCO2 should be 14, which is exactly correct. Therefore this patient has a perfectly compensated metabolic acidosis. Since the patient was not in shock or uremic, and his urine had no ketones on dip, ingestions (ASA, Methanol, Ethylene Glycol etc.) must be considered. ASA usually has a profound respiratory alkalosis, and mild metabolic acidosis. Methanol and EG both are toxins that are metabolized to acids, and cause in addition to an anion gap an osmolar gap. This patient had a large osmolar gap, oxalate crystals in the urine and a high ethylene glycol level. We initiated immediate intravenous ethanol treatment and called in the dialysis team. Volume (NS) and bicarbonate normalized the peaked T waves on his initial ECG. This patient did well.
- 2. A quick glance at these "numbers" might have fooled you before the lecture, and look normal. But the patient looked sick, and you now have the correct reflex to calculate the anion gap on EVERY SMA-6 you interpret. This patient has an anion gap of 27, and must have a metabolic acidosis, with the same differential diagnosis as above. In every patient we see with a metabolic acidosis, we next utilize Winter's Formula to calculate respiratory compensation. 1.5 (22) + 8=41. This is close to the patient's pCO<sub>2</sub> of 39, so there is no respiratory disorder. The only other disorder this patient could have is a metabolic alkalosis (since there are only 4 disorders, and we have ruled out respiratory disorders). This is where we need to calculate the "delta-delta". Assume a normal gap is 10. This patient's anion gap is 27, or 17 additional unmeasured anions have been added to his serum. These anions were buffered at a 1:1 ratio by bicarbonate. Therefore his bicarbonate dropped from 39 (17 + 22) to 22. His "bicarbonate equivalent" is 39, which is clearly a metabolic alkalosis. He had 4+ ketones in his blood (starvation ketosis) and a severe metabolic alkalosis from vomiting. He was hydrated carefully with D5NS, given Compazine and clear liquids, and was dialyzed and discharged the next day without an anion gap.

- 3. This patient appeared ill and dry. An IV of NS was initiated wide open, and a urine dipstick revealed trace ketones. The ABG is consistent with a severe metabolic alkalosis, as the bicarbonate and pCO<sub>2</sub> are elevated. Her SMA-6 reveals an anion gap of 8 (normal), an elevated bicarbonate and BUN, and severe hypokalemia. Remember that only 2% of your total body K+ is extracellular, so an initial serum K+ of 2.9 represents profound total body deficits (300-1000 mEq). Obviously we correct most acid-base and electrolyte abnormalities at the rate they occurred, and cannot give greater then 10 mEq/hour of K+ due to potential cardiac toxicity. This patient generated her metabolic alkalosis by persistent vomiting (loss of Cl-, and volume), and is maintaining the alkalosis by the kidney (aldosterone driven reabsorption of sodium and bicarbonate in this chloride depleted state). Compensation is calculated based on an increase of pCO<sub>2</sub> by .6 for each 1 mEq/L increase in bicarbonate. Her bicarbonate is 14mEq above normal, so 14 x .6 = 8. pCO<sub>2</sub> should be 48, which it is. Remember you cannot "hypoventilate" much beyond 48-50 pCO<sub>2</sub> without the hypoxic drive kicking in. This patient was treated with volume expansion and KCl until her pancreatitis (due to a gallstone) resolved.
- This patient was very ill, hypotensive and febrile. His initial ABG was confusing, with an alkalotic pH, 4. normal pCO2 and elevated calculated bicarbonate, (? metabolic alkalosis). We started NS, did a finger stick BS (>400) initiated a fever workup, and received the SMA-6. The reflex calculation of the AG pays off, and reveals an anion gap metabolic acidosis, (gap is 28), with the differential as discussed above. Winter's Formula tells us the  $pCO_2$  should be 53, and the patient's  $pCO_2$  is 40 (respiratory alkalosis). The differential of this disorder includes ASA, pulmonary conditions (like pneumonia), early sepsis, liver disease, early hypovolemic shock. How can we tell if this ill patient has a triple disturbances (i.e. metabolic alkalosis)? Lets do the dreaded "delta-delta" again. Normal gap is 10, his is 28. This patient has 28-10, or 18 unmeasured anions added to his serum. This brought his bicarbonate down 18 by buffering. His bicarbonate equivalent is 18 (the delta-delta) plus his serum bicarbonate (30), which equals 48! This clearly represents a metabolic alkalosis, or triple disturbance. This patient was in DKA (gap acidosis), volume depleted due to vomiting and an osmotic diuresis (metabolic alkalosis) and had pneumonia and sepsis (respiratory alkalosis) Aggressive treatment with fluids (NS), then insulin and potassium, coupled with antibiotics and oxygen had him turning the corner before leaving the ED. He grew pneumococcus from his blood.
- This young woman had no prior medical history, and presented short of breath and tachycardic. A line 5. of NS was initiated wide open, and finger stick BS revealed > 400. Urine dip showed 4+ glucose and trace ketones. The ABG reveals a profound metabolic acidosis, with a low  $pCO_2$  and HCO3. The SMA-6 confirms an anion gap metabolic acidosis (gap of 26), pseudo-hyponatremia (remember for every 100 your glucose is elevated above normal, your serum sodium drops 1.6), hyperglycemia and hypokalemia (especially in light of the low pH). Winter's Formula (a reflex which tells you what the  $pCO_2$  should be in a compensated metabolic acidosis) is 1.5 (8) + 8 = 20. Her  $pCO_2$  is 20, so this is a perfectly compensated metabolic acidosis. Lets check and see if she has a metabolic alkalosis. 26 (her gap) - 10 (normal gap) = 16. Her bicarbonate equivalent is 8 (her bicarbonate) plus 16 or 24, which is a normal bicarbonate. She does not have a metabolic alkalosis! While this case is clearly DKA you should always consider the other possible causes of an anion gap metabolic acidosis (lactate, uremia, ingestions), and pursue these diagnoses as appropriate. She did well with volume, insulin, potassium, magnesium and oral phosphate replacement in the hospital. The next morning her number's revealed: Na 143 K 3.8 Cl 119 HCO3 12 Glucose 310. Is she still in DKA? The answer is NO! While she still has low bicarbonate, her anion gap is only 12. She now has a non-anion gap metabolic acidosis, or a hyperchloremic non-gap metabolic acidosis. This is normal post-treatment of DKA. She has lost bicarbonate equivalent in the form of ketones in her urine, that were replaced with Cl in the IV NS she was hydrated with. She can safely be switched over to SO insulin, and her kidneys will regenerate bicarbonate over time.

- 6. I saw this patient recently in our ED, and the resident on duty told me his numbers were "normal", even though the patient looked sick. A quick glance at the ABG and SMA-6 is misleading. The patient has an anion gap of 25, and his pCO<sub>2</sub> using Winter's Formula should be 41 + 2, (which it is). This patient has a metabolic acidosis with respiratory compensation. How can he have a normal pH? The only way is a concomitant metabolic alkalosis. Let's do the "delta-delta" once again. The patient's gap -10(normal) is 15. This patient has 15 unmeasured anions added to his serum. Assuming his bicarbonate buffered the acid at a ratio of 1:1, his bicarbonate dropped from 37 to 22. His bicarbonate equivalent is 37, which is clearly a metabolic alkalosis. This patient has a mixed disorder, or concomitant metabolic acidosis and metabolic alkalosis. This patient has classic alcoholic ketoacidosis (AKA). Alcoholics have poor glycogen stores, and when they binge and suffer pancreatitis or gastritis and begin to vomit, they generate a severe ketoacidosis. The metabolic alkalosis is due to the persistent vomiting and loss of chloride and volume, which generates the alkalosis. Remember the kidney maintains the alkalosis via aldosterone. This patient responded to D5NS, potassium, thiamine, magnesium (his was 0.9), and a little Ativan for the "shakes". This is one of the few causes of a metabolic acidosis that can be treated on the floor, as all these patients really need is volume and glucose to turn off the acidosis. To be complete, we did an osmolar gap (to rule out methanol and ethylene glycol), and considered the other causes of anion gap metabolic acidosis. This patient's gap normalized in 4 hours with the above therapy.
- 7. This CCU nurse at first gave me no additional history. I talked her into a SMA-6, and IV hydration because she was orthostatic and clinically was dry. Her SMA-6 reveals hyponatremia, hypokalemia, and a very high bicarbonate (which can only be due to a severe metabolic alkalosis or metabolic compensation for a severe respiratory acidosis, of which the later is highly unlikely). Her anion gap is 14, which is slightly elevated. Her ABG confirmed alkalemia, which is certainly metabolic. Remember your pCO<sub>2</sub> will go up 0.6 for each mEq your HCO3 is above 24. Her bicarbonate is 18 mEq above normal, so  $18 \ge 0.6 = 11$ , or her pCO<sub>2</sub> should be 51mmHg. Hers is 50, so she has a compensated metabolic alkalosis. On further exam I noted poor dentition (for an attractive woman) and scratch marks on the back of her right hand. A urine sample revealed trace ketones (which probably accounts for the small anion gap) and her urine chloride was "zero". This confirmed my suspicion that she was losing chloride via the GI tract, and I confronted her with her diagnosis: bulimia. She broke down and admitted her eating disorder, agreed to a psychiatric evaluation while I hydrated her with NS and 40mEq of KCl/liter in the ED. She did extremely well, and still sends me a Christmas card annually! If she had been abusing diuretics her urine chloride would have been elevated, or at least present. Again, rapid interpretation of the numbers can guide you to the most likely diagnosis, and initiate appropriate therapy.
- 8. This patient was very ill and required immediate fluids, oxygen and pressors. A quick glance at the ABG reveals a probable respiratory alkalosis (alkalemia, low pCO<sub>2</sub>). The SMA-6 looks relatively normal, but the anion gap is 22, consistent with a metabolic acidosis. We now utilize Winter's Formula, 1.5 (22) + 8 ± 2 = pCO<sub>2</sub>, or 41 mmHg. Her pCO<sub>2</sub> is 25, so this patient has a respiratory alkalosis. The only other disturbance she can have is a metabolic alkalosis. You should be a pro at this by now. Take the patient's gap (22), subtract a normal gap (10) to get the "delta-delta" (12). This represents the unmeasured anions added to her serum, which is buffered by bicarbonate. Therefore her bicarbonate dropped from 20 (her bicarbonate now) + 12 (the delta-delta), or 32. Her bicarbonate equivalent is 32, which represents a metabolic alkalosis. She has a triple disturbance, which was due to uro-sepsis (E. Coli grew in her blood). The metabolic acidosis was due to lactate, respiratory alkalosis due to sepsis, and the metabolic alkalosis was secondary to the furosemide she was on at home, and being very dry. She was later intubated, and admitted to the ICU. Her clinical presentation fit her numbers!

- 9. This patient had acute symptoms on top of a chronic condition. His anion gap is only 9, despite a low bicarbonate (18). The ABG reflects a respiratory alkalosis (the usual disturbance in asthma), and severe hypoxemia (alveolar-arterial gradient of 40). Remember Alveolar O2= FIO2 (760-pH2O) 1.2 (pCO<sub>2</sub>). ApO2 = .20 (760-47) 1.2 (28), or 109. Aa gradient is ApO2 (109) apO2 (69) = 40. Normal Aa gradient in a young non-smoker is about 8-10 mmHg. Patients with asthma have V/Q mismatch and some shunting. Back to the Acid-Base. Compensation for a respiratory alkalosis is a decrease in bicarbonate of 5 for every 10 mmHg the pCO<sub>2</sub> is below normal. His pCO<sub>2</sub> is 28, or 12 mmHg below normal (40). His bicarbonate should be approximately 18, (which it is) therefore he has a compensated respiratory alkalosis. The low bicarbonate in this situation tells you the patient has been ill for several days (his kidneys have had time to excrete bicarbonate), and this patient probably will not respond to one albuterol treatment and steroids. He required admission to the hospital for aggressive treatment of his asthma.
- 10. This patient had the appearance of a typical chronic bronchitic. He was overweight and cyanotic. The cyanosis and overt right heart failure sometimes leads to these patients being described as "bluebloaters". His SMA-6 has an anion gap of 10 (normal), and is most remarkable for high bicarbonate. His ABG reveals a respiratory acidosis, with pCO<sub>2</sub> of 70. Compensation would be renal retention of bicarbonate, 3.5 mEq for each 10mmHg the pCO<sub>2</sub> is above normal (40). His bicarbonate should be about 35 mEq, and it is only 30. This implies either a metabolic acidosis (there was no clinical reason for this) or an acute respiratory acidosis superimposed on the chronic respiratory acidosis. With bicarbonate of 30 (6 above normal) one would expect his baseline pCO<sub>2</sub> to be about 60 mmHg. His old records later confirmed that his baseline pCO<sub>2</sub> was indeed 60. So the ABG confirmed that he had an acute exacerbation of his COPD, which was superimposed on a chronic respiratory acidosis. CPAP and aggressive management of his COPD helped keep him off a ventilator.
- 11. This patient is gravely ill. He has an anion gap of 13, which is normal. There is no anion gap, no metabolic acidosis yet the patient is comatose with 4+ ketones in his urine. This should immediately have you consider isopropyl alcohol as the culprit of his condition. Calculate the osmolar gap. Calculated osmolality is 2(141 Na) + 90 (glu)/18 + 14 (bun)/2.8 + BAL/5 = 292. Measured (338)-Calculated (292) = 46. Isopropyl alcohol increases osmolality 0.17mOsm per 1mg% isopropyl. Therefore the Isopropyl level is approximately 46/. 17= 270mg%. This patient requires immediate airway management and dialysis.
- 12. The most important fact is that your patient looks much improved, even though the numbers look bad. His initial anion gap is 23, which is evidence of a metabolic acidosis. A normal anion gap being 10, 23-10 is 13, or this patient has a delta-delta of 13. His bicarbonate went from 27 to 14. Bicarbonate of 27 is close enough to 24 to call this normal, and excludes a metabolic alkalosis. His ABG on arrival to the ED is normal, and does not reflect the expected pCO<sub>2</sub> of a patient with bicarbonate of 12 (his pCO<sub>2</sub> should be 26 using Winter's Formula). What most likely happened? The patient had a seizure at the scene, had a transient lactic acidosis that was reflected by the "scene" electrolytes, and has since resolved. A single seizure produces a pH of 7.15, but corrects within 15 minutes. Electrolytes can often help solve mysteries!
- 13. This is an unusual cause of an elevated anion gap. Because this patient just had neck surgery, the natural worry is the function of her parathyroid glands, which leaves her at risk for hypocalcemia and hypomagnesemia. There is no evidence of an ongoing metabolic acidosis, so one must consider a decrease in unmeasured cations. She did indeed have severe hypo-calcemia and magnesemia, and her gap normalized with cation replacement.

- 14. This patient has an anion gap of 10, which is normal. She does have a low bicarbonate, high chloride and acidotic pH, so we must suspect a non-anion gap metabolic acidosis. Lets do Winter's Formula, which is accurate for both gap and non gap metabolic acidosis.  $pCO_2 = 1.5(13) + 8 \pm 2$ , or 28. The patient's  $pCO_2$  is 30, which means she has a compensated metabolic acidosis. Further history elicits admission of glue sniffing (toluene/hydrocarbon toxicity), and the severe hypokalemia and muscle weakness is consistent with the renal tubular acidosis these patients can develop. This patient is at risk for quadriparesis and rhabdomyolysis. Hospitalization was required.
- 15. This patient appeared ill, and had very abnormal numbers. Her anion gap is 23, which is evidence of a metabolic acidosis. Lactate, ketones, uremia and ingestions are in the Dx. Using Winter's Formula, the pCO<sub>2</sub> should be 53, so she also has a respiratory alkalosis. Because of the anion gap acidosis and the initial high bicarbonate, one must suspect a metabolic alkalosis as well. Her gap 10 (normal gap) is 23-10 =13. Her bicarbonate came down 13 to its current level. Her bicarbonate equivalent is 13 + 30 (her current bicarbonate) or 43, which is evidence of a metabolic alkalosis. Her urine had 2+ ketones, and this patient had a triple disturbance. Metabolic acidosis (DKA, AKA, ketones), metabolic alkalosis (vomiting) and respiratory alkalosis (hepatic disease from alcohol abuse).

#### **Select Bibliography**

#### In my opinion these are the most readable reviews written on this topic.

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