MEDICINE

432 Team

16 Acid Base Disorders

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COLOR GUIDE: • Females' Notes • Males' Notes • Important • Additional

Objectives

1. State the normal value for PH, PCO_2, and HCO_3.
2. Understand the basic mechanism of acid base disturbance.
3. Interpret basic acid base disturbance.
4. List common differential diagnosis for different acid base disorder.

Introduction: (From Kumar)

The concentration of hydrogen ions in both extracellular and intracellular compartments is extremely tightly controlled, and very small changes lead to major cell dysfunction. The blood pH is tightly regulated and is normally maintained at between 7.38 and 7.42. Any deviation from this range indicates a change in the hydrogen ion concentration [H+] because blood pH is the negative logarithm of [H+]. The [H+] at a physiological blood pH of 7.40 is 40 nmol/L. An increase in the [H+] – a fall in pH – is termed acidaemia. A decrease in [H+] – a rise in the blood pH – is termed alkalaemia. The disorders that cause these changes in the blood pH are acidosis and alkalosis, respectively.

Normal Values:

- **Normal arterial blood pH** = 7.35 – 7.45
- **$PaCO_2$** = 35-45
- **Serum HCO_3**= 22-26
- **Anion gap** = 8-12 *(in Medscape 8-16)*

Primary Disorder				
Primary Disorder	**Problem**	**pH**	**HCO_3**	**P_aCO_2**
Metabolic acidosis	gain of H^+ or loss of HCO_3	↓	↓	↓*
Metabolic alkalosis	gain of HCO_3 or loss of H^+	↑	↑	↑*
Respiratory acidosis	Hypoventilation *(retention of CO_2 inside the body)*	↓	↑*	↑
Respiratory alkalosis	Hyperventilation *(washing CO_2 out of the body)*	↑	↓*	↓

*Compensatory response.

In metabolic disturbances, respiratory compensation is almost *immediate* while in respiratory disorders, compensatory changes in bicarbonate occur via *long-term* adjustments *(by kidneys mainly).*

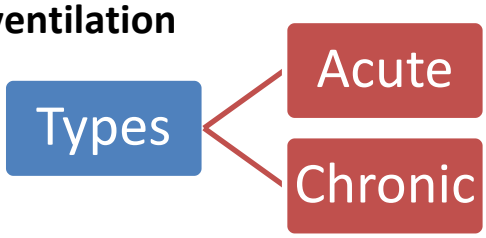
(From Davidson's) Patients with disturbances of acid-base balance may present clinically either with the effects of tissue malfunction due to disturbed pH (such as altered cardiac and CNS function), or with secondary changes in respiration as a response to the underlying metabolic change (e.g. Kussmaul respiration during metabolic acidosis).

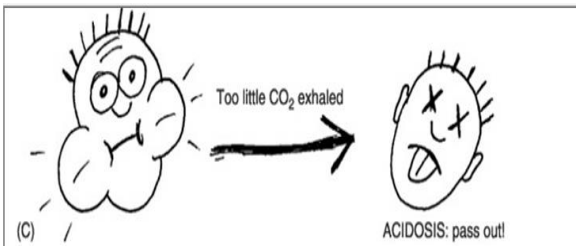
The clinical picture is often dominated by the cause of the acid-base change, such as uncontrolled diabetes or primary lung disease. Frequently the acid base disturbance only becomes evident when the venous plasma bicarbonate concentration is noted to be abnormal, or when a full **ABG *(Arterial blood gas)*** analysis shows abnormalities in the pH, pCO_2 or bicarbonate.

Respiratory Acidosis:

➢ Primary Mechanism:

Hypoventilation





➢ Causes: anything will lead to hypoventilation *(go through the whole pathway to make it easier)*

1. CNS: (by suppression of respiratory centers in the brainstem)

- Head trauma
- Drugs (sedatives e.g., morphine, Narcotics or opiate)
- Brain tumors
- Sudden cessation of blood circulation (stroke)
- Neuro-infections

2. Peripheral nerves:

- Guillain-Barre syndrome *(demyelination of peripheral nerves, patient presents with ascending paralysis, diagnosed by vital capacity + ABG)*

3. Neuromuscular junction:

- Myasthenia gravis *(diagnosed by vital capacity + ABG)*

4. Chest wall:

- Scoliosis
- Kyphosis (تحدب)
- Muscular dystrophy

5. Bronchial tree:

- COPD
- Airway obstruction
- Severe pneumonia
- Chest trauma
- Pneumothorax

Chronic Respiratory Acidosis:

- pH is normal
- pCO_2 is elevated
- Renal mechanisms increase the excretion of H^+ within 24 hours (By producing HCO_3 which results in increase in the level of HCO_3) and may correct the resulting acidosis caused by chronic retention of CO_2 to a certain extent

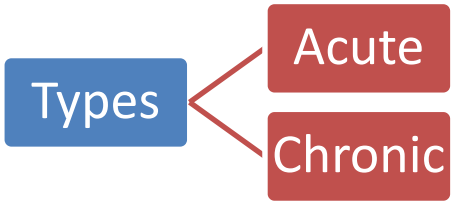
➢ Causes of Chronic Respiratory Acidosis:

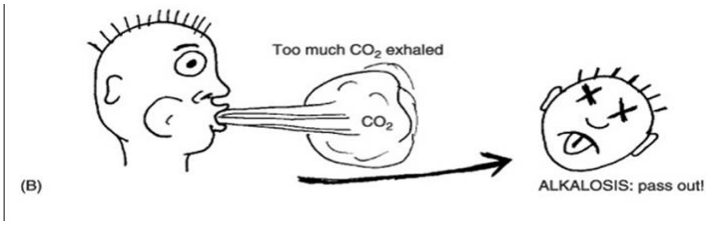
- Chronic lung disease (COPD)
- Neuromuscular disease
- Extreme obesity
- Chest wall deformity (scoliosis, Kyphosis)
- Muscular disease (muscular dystrophy)

Respiratory Alkalosis:

➢ Primary Mechanism:

Hyperventilation





➢ Causes: anything will lead to hyperventilation

1-CNS: (by Activation of respiratory centers in the brainstem)

- Pain *(patient under stress usually develop hyperventilation)*
- Drugs
- Sepsis
- Fever
- Pregnancy
- Anxiety

2-Hypoxemia

3-Pulmonary causes:

- Pulmonary embolism
- Restrictive lung disease + Bronchial asthma -primarly-

4-Iatrogenic:

- Overaggressive mechanical ventilation

5-Others:

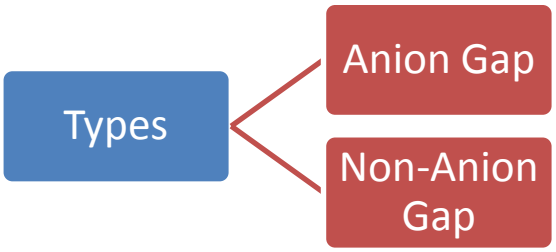
- Hepatic failure
- Severe congestive heart failure

Asthma is a special condition where you might face both acidosis and alkalosis in different stages:

At the moment of attack, patient will suffer hyperventilation → respiratory alkalosis (in ER usually)

If alkalosis is not treated, after a while, his chest wall muscles will get fatigue → he will go into hypoventilation → resp. acidosis

Metabolic acidosis:



➢ Causes:

- **Increase acid production**
- **Decrease acid excretion***
- **Loss of bicarbonate by one of two ways:**

1- Loss of HCO_3 (like diarrhea)

2- Combining with H^+ (to form $CO_2 + H_20$)

*Acid secretion from tubular renal cells to the lumen (urine) will lead to Bicarbonate reabsorption (indirect reabsorption) so, any reduction of acid (H+) excretion will lead to a reduction in (HCO_3-) absorption → acidosis.

Sources of H+:

1- *Endogenous:* Lactic acidosis, DKA *(diabetic ketoacidosis)*, Starvation KA *(ketoacidosis)*, Renal failure

2- *Exogenous:* Alcohol consumption

Anion Gap Calculation: *(First thing to do when you figure out that the case is metabolic acidosis, to help you in DDx)*

Anion Gap = Cations – Anions or Anion Gap = (Na + K) – (Cl + HCO_3)

**The potassium (K) is an cation with insignificant value, so we can neglect it and use Na alone →*

Anion Gap = Na – (Cl + HCO_3)

❖Causes of Increased Anion Gap: (MUD PILES)

- **M**ethanol
- **U**remia
- **D**iabetic KA/ Starvation KA
- **P**araldehyde
- **I**soniazid
- **L**actic acidosis
- **E**thanol (Alcohol)/Ethylene Glycol
- **S**alicylates (Aspirin)

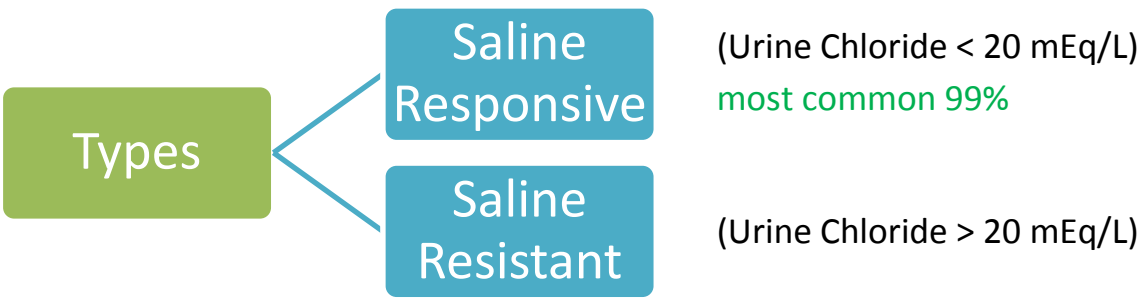
❖Causes of Non-Anion Gap:

- GI loss of HCO_3: Diarrhea *(you might say: decrease in HCO_3 should be associated with high AG according to the formula. You're right, but what happens in this case is: you lose HCO_3 (negativity decreased) → Kidneys maintain AG by reabsorbing more Chloride (negativity increased))*
- Renal Tubular Acidosis (RTA)
- Others

Metabolic Alkalosis:

➢Causes:

- **Loss of acid (H^+)** *(loss of fluid, cause HCO_3 will be concentrated → concentration alkalosis)*
- **Gain of bicarbonate (HCO_3)** *(e.g., tablets, injection)*



➢ Causes of Saline Responsive:

- **GI loss of H^+:** Vomiting, NGT *(nasogastric tube)* drainage, villous adenoma, chloride diarrhea
- **Diuretics**

How can diarrhea be a cause for both acidosis and alkalosis?

It depends on the components lost. If you're losing HCO_3 → acidosis

If you're losing fluid → alkalosis (concentration alkalosis)

➢ Causes of Saline Irresponsive:

- **1^0 hyperaldosteronism** (eg. Conn's)
- **2^0 hyperaldosteronism** (e.g., renovascular dis. Rennin-secreting tumor)
- **Others**

Steps in Acid-Base Analysis:

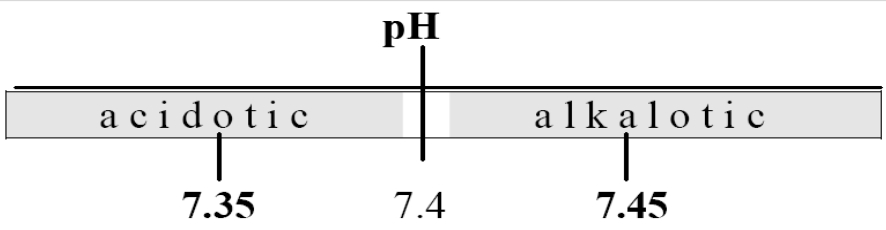
Step 1: *Acidemic or Alkalemic?*

Step 2: *Is the primary disturbance respiratory or metabolic?*

- ***a.*** *Is the respiratory disturbance **acute or chronic**?*
- ***b.*** *For a metabolic acidosis, is there an increased **anion gap**?*
- ***c.*** *Is the respiratory system **compensating** adequately for a metabolic disturbance?*
- ***d.*** *Is it a single problem or a combination of two problems?*
- ***e.*** *Are there other metabolic processes present in a patient with an increased anion gap metabolic acidosis?*

➢ Step 1: Acidemic or Alkalemic?

- Normal arterial blood pH = 7.35 – 7.45 (Normal patient or **Chronic** problem *-pt is compensating-* you should do the next step to know the real condition)
- **Acute acidemic**: pH < 7.35
- **Acute Alkalemic**: pH > 7.45



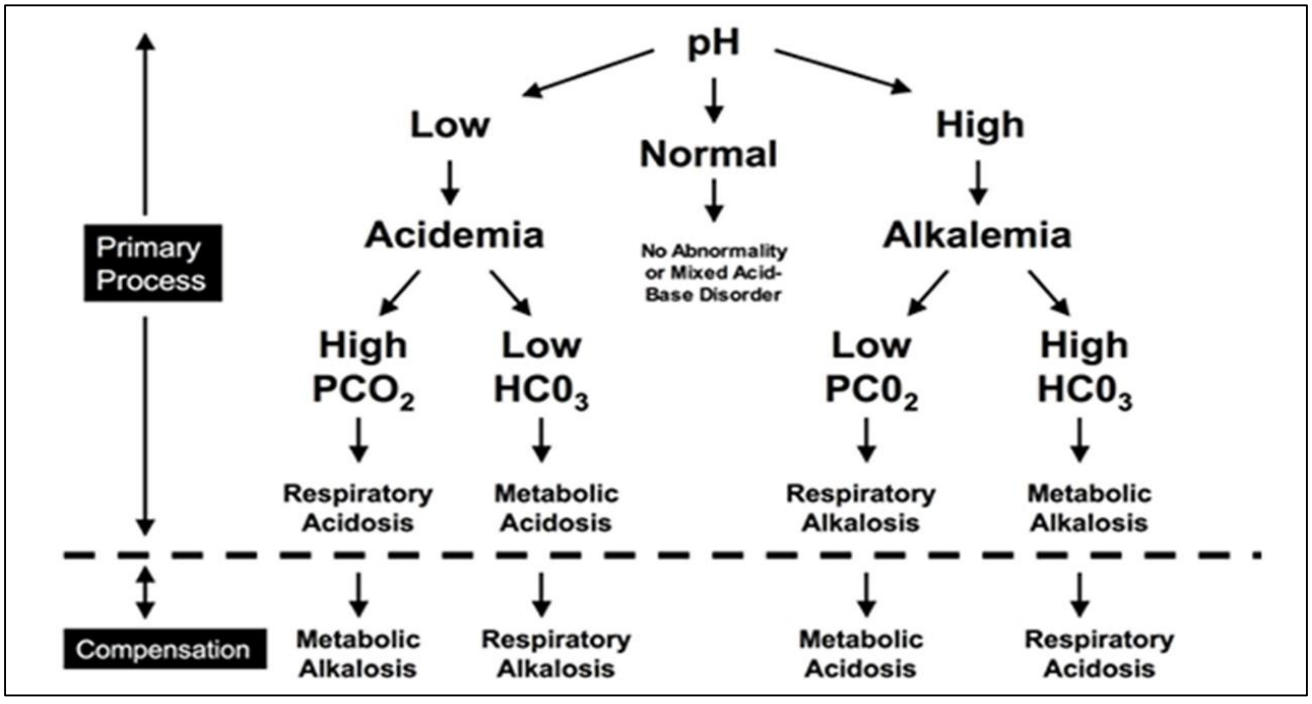
➢ Step 2: is the primary disturbance Respiratory or Metabolic?

- P_aCO_2 = 35-45
- Serum HCO_3^-.= 22-26
- **Respiratory → any alteration related to PCO_2**
- **Metabolic →any alteration related to HCO_3**

➢ Step 3: is the respiratory disturbance Acute or Chronic?

- In general, the primary disturbance is followed by a compensatory process, as the body attempts to bring the pH back towards the normal range.

1. If the patient has a primary respiratory acidosis: the compensatory process is a metabolic alkalosis
2. If the patient has a primary respiratory alkalosis: the compensatory process is a metabolic acidosis
3. If the patient has a primary metabolic acidosis: the compensatory process is a respiratory alkalosis (hyperventilation)
4. If the patient has a primary metabolic alkalosis: the compensatory process is a respiratory acidosis (hypoventilation)



Acute respiratory acidosis:

For every 10 mmHg increase in **$PaCO_2$**, the **HCO_3^-** increase by 1 mEq/l

Chronic respiratory acidosis :

For every 10 mmHg increase in **$PaCO_2$**, **HCO_3^-** increase by 3-3.5 mEq/l

Acute respiratory alkalosis :

For every 10 mmHg decrease in **PaCO2**, **HCO_3^-** decrease by 2 mEq/l

Chronic respiratory alkalosis :

For every 10 mmHg decrease in **$PaCO_2$**, **HCO_3^-** decrease by 4-5 mEq/l

You may ask, how in acute case pt presents with abnormal pH while he's compensating? Pt actually is only trying to compensate (not fully compensated yet) and you want to make sure that his compensation is working appropriately.

MEMORIZE THE NUMBERS

- we can determine if the respiratory acidosis is **Acute or Chronic** based on the **compensation process**;
  1. **Acute** if the HCO_3 is **in the normal range** or slightly increased B/C it takes times for the kidney to compensate
  2. **Chronic** if the HCO_3 is **increased** & the pH return to its normal state

- we can determine if the respiratory alkalosis is **Acute or Chronic** based on the **compensation process**;
  3. **Acute** if the HCO_3 is **in the normal range** or slightly decreased B/C it takes times for the kidney to compensate
  4. **Chronic** if the HCO_3 is **decreased** & the pH return to its normal state

	pH	$PaCO_2$	HCO_3	
Respiratory Acidosis				
Acute	< 7.35	> 45	Normal	(important)
Partly Compensated	< 7.35	> 45	> 26	
Compensated (Chronic)	Normal	> 45	> 26	(important)
Respiratory Alkalosis				
Acute	> 7.45	< 35	Normal	(important)
Partly Compensated	> 7.45	< 35	< 22	
Compensated (Chronic)	Normal	< 35	< 22	(important)

***Failure to compensate suggests additional acid base problem**

➢ Step 4: For a metabolic acidosis, is there an increased anion gap?

- AG = $[Na^+]$ - ($[Cl^-]$ + $[HCO_3]$)
- Normal AG = 8-16
- If **increased = AG Metabolic Acidosis**
- If **normal = Non-AG Metabolic Acidosis**

➢ Step 5: Is the respiratory system compensating adequately for a metabolic disturbance?

Metabolic acidosis:

For every 1 mEq/l decrease in **HCO_3**, **PCO_2** decreases by 1 mmHg

Metabolic alkalosis:

For every 1 mEq/l increases in **HCO_3**, **PCO_2** increases by 0.6 mmHg

In case of metabolic abnormalities, respiratory system starts compensating very quickly → no significant difference between acute & chronic cases.

➢ Step 6: Is it a single problem or combination of two problems?

1st: detect the primary problem

2nd: calculate compensation

3rd: compare the findings with the value expected

e.g., 67 women with hypotension, diabetes & COPD presented with shortness of breath. pH= 7.21, pCO_2=40, HCO_3=5

1st: Look at the abnormal value. In this case, HCO_3 is decreased → primary problem is metabolic acidosis.

2nd: in metabolic acidosis, I expect a compensation where CO_2 will be decreased by a value similar to HCO_3 → 1:1 ratio → HCO_3 decreased by: *24-5 =19, CO_2 should be 40-19= 21*

3rd: provided CO_2 value =40 → no respiratory compensation → there is an underlying respiratory acidosis.

➢ Step 7: Are there other metabolic processes present in a patient with an increased anion gap metabolic acidosis? *(This step is for your information- Not included in the lecture)*

- Considering that **AG = 12** as normal value (average b/w 8-16)

We take the patient anion gap and subtract it by 12 & that will give us the Δ Gap

- **patient AG – 12 (normal AG) = Δ Gap**

The Δ Gap tell us how many molecules of HCO_3 we should have lost, so for example the Δ Gap = 8 then there is 8 molecules of HCO_3 should have been lost

So by common sense if we took the Δ Gap & add it to the patient HCO_3 it should equal 22-26 & it means that the patient doesn't has any additional metabolic process going on

- **Δ Gap + Patient HCO_3 = 22-26** (no additional metabolic process)

But if the value is more than we expected (>26), that means there is a gaining of HCO_3 & the patient probably has an additional metabolic process occurring which is Metabolic alkalosis

- **Δ Gap + Patient HCO_3 > 26** (Metabolic Alkalosis)

- & if the value is less than we expected (<22), that means there is a loss of HCO_3
- & the patient probably has an additional metabolic process occurring which is Non-AG Metabolic Acidosis

- **Δ Gap + Patient HCO_3 < 22** (Non-AG Metabolic Acidosis)

<u>In Summary:</u>

- **Δ Gap + Patient HCO_3 = 24** (no additional metabolic process)
- **Δ Gap + Patient HCO_3 > 26** (Metabolic Alkalosis)
- **Δ Gap + Patient HCO_3 < 22** (Non-AG Metabolic Acidosis)

	pCO_2	HCO_3	condition
Normal pH	-	-	normal
	↑	↑*	Chronic respiratory acidosis
	↓	↓*	Chronic respiratory alkalosis
High pH	-	↑	Metabolic alkalosis combined with respiratory alkalosis *(no respiratory compensation)*
	↓	-	Acute respiratory alkalosis *(no kidney compensation)*
	↑*	↑	Metabolic alkalosis *(compensated-absence of combined respiratory alkalosis)*
	↓	↓*	Acute on top of chronic respiratory alkalosis *(high pH → acute, compensation → chronic)*
Low pH	-	↓	Metabolic acidosis combined with respiratory acidosis *(no respiratory compensation)*
	↑	-	Acute respiratory acidosis *(no kidney compensation)*
	↓*	↓	Metabolic acidosis *(compensated-absence of combined respiratory acidosis)*
	↑	↑*	Acute on top of chronic respiratory acidosis *(low pH → acute, compensation → chronic)*

Rules you need to consider when approaching the diagnosis:

A. pH:

1. Normal → either chronic or normal condition.

2. High → acute or acute on top of chronic condition (means that the patient is having a chronic problem but suddenly a new acute state arises) to figure out the real situation, do the next step

B. CO_2, HCO_3 levels:

1. Alteration in one of them → acute. (HCO_3 → metabolic, CO_2 → respiratory)

2. Alteration in both of them (either both high or both low) chronic (normal pH) or acute on top of chronic (abnormal pH).

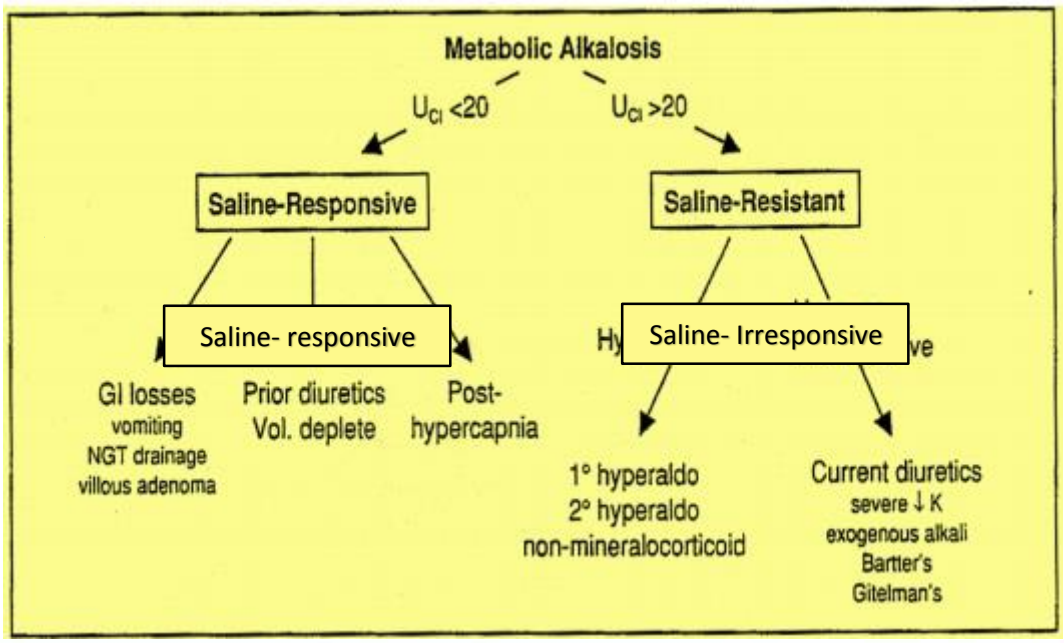
Treatment depends on the primary problem. *E.g., cause is drug overdose → try to revers it*

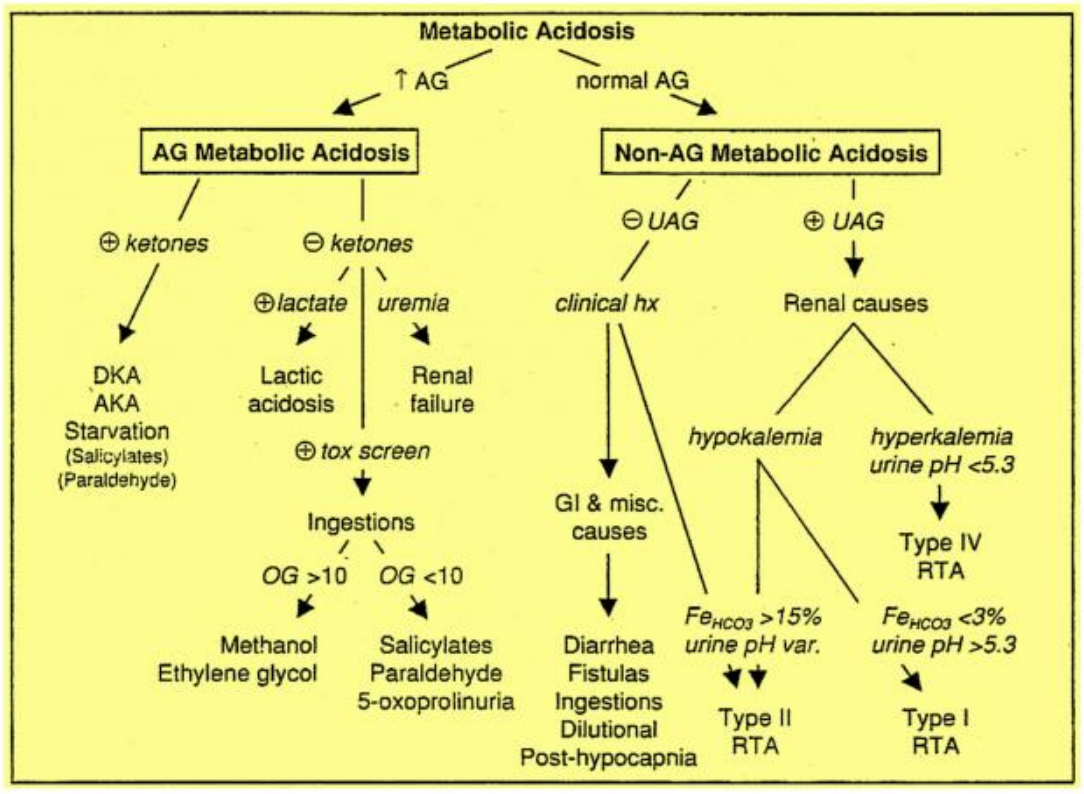
In a respiratory problem, kidneys try to compensate, as long as it takes time to compensate, you may classify it as acute or chronic cases.

This is not the same with metabolic problem because respiratory system compensate quickly, I expect to see signs of compensation even in acute cases. Therefore, you may classify it as:

There is compensation → no additional respiratory problem

No compensation → there is respiratory problem





No need to memorize the details of RTA types.
You should know that you develop metabolic acidosis generally by:
1- Losing bicarbonate: in diarrhea or renal tubular acidosis
2- Gaining acid, either internally such as lactic acidosis, ketoacidosis or externally i.e. aspirin overdose, excessive alcohol intake.
3- Osmolar gap (OG) is to know if there are substances contributes to the osmolality such as alcohol or salicylates

SUMMARY

1. Normal arterial blood pH = 7.35 – 7.45
2. Normal $PaCO_2$ = 35-45
3. Normal HCO_3= 22-26
4. Normal Anion gap = 8-16
5. Any disturbance in these values will lead to ABD **(you must know which one from the Q)**
6. The primary cause of Respiratory Acidosis is **hypoventilation.** It could be acute or chronic.
7. The primary cause of Respiratory Alkalosis is **hyperventilation**. It could be acute or chronic.
8. The primary cause of Metabolic Acidosis is ↑**H+,** ↓**HCO_3-**. It could be anion gap or non-anion gap acidosis.
9. The primary cause of Metabolic Alkalosis is ↓**H+,** ↑**HCO_3-**. It could be saline responsive or resistant.

Primary Disorder				
Primary Disorder	**Problem**	**pH**	**HCO_3**	**P_aCO_2**
Metabolic acidosis	gain of H^+ or loss of HCO_3	↓	↓	↓*
Metabolic alkalosis	gain of HCO_3 or loss of H^+	↑	↑	↑*
Respiratory acidosis	hypoventilation	↓	↑*	↑
Respiratory alkalosis	hyperventilation	↑	↓*	↓

The cases from Team 431 are very important! You should read & answer it.

432 Medicine Team Leaders

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