酸鹼異常

腎臟內科

學習目標

PGY	UGY
知識 1.酸鹼異常相關的影像檢查 2.腎切片檢查的照護 3.酸鹼異常病人的處理程序 4.透析病人的照護 5.透析相關併發症的防治	**知識** 1.酸鹼異常的定義 2.酸鹼異常的臨床表現 3.酸鹼異常的病理生理機制 4.酸鹼異常的診斷流程 5.尿毒症的病理生理機制 6.透析的基本原理 7.酸鹼異常相關的實驗室檢查判讀，包括BUN/Cr、Ca、P、電解質、動脈血氣體分析、尿液分析、尿鈉、血清及尿之滲透壓、計算鈉離子之fraction excretion 8. 照會做腎超音波之適應症及判讀 **技能** 1.酸鹼異常相關的病史詢問 2.酸鹼異常相關的身體檢查

Normal acid-base balance

- Arterial PH between: 7.35-7.45, mean 7.40
- PCO_2 : 40 $\pm$ 5 mmHg
- HCO_3^- :24 $\pm$ 2 mEq/L
- Anion gap (12 $\pm$ 2)

- Vein gas: pH:7.35, PCO2: 46, HCO3:24-26

Acid Base Balance

- Assessment of status via bicarbonate-carbon dioxide buffer system
  - $CO_2 + H_2O \text{ <--> } H_2CO_3 \text{ <--> } HCO_3^- + H^+$

$$\mathbf{PH = Pka + \log \frac{[HCO_3^-]}{0.03PaCO_2}}$$

$$\mathbf{= 6.1 + \log \frac{20}{1}}$$

Classification of Acid-basic Disorder

- **PH, $PaCO_2$, HCO_3^- are three important parameters in acid-basic disorder evaluation.**

- **Complementary: PH is normal**
- **Dis-complementary: PH is abnormal.**

Classification of Acid-basic Disorder

	PH	PaCO2	HCO_3^-
Resp. acidosis	↓	↑↑	↑
Resp. alkalosis	↑	↓↓	↓
Meta. acidosis	↓	↓	↓↓
Meta. alkalosis	↑	↑	↑↑

Respiratory Acidosis

- ↓PH, ↑PCO_2, ↓Ventilation
- Causes
  - CNS depression
  - Pleural disease
  - COPD/ARDS
  - Musculoskeletal disorders

Respiratory Acidosis

- Acute vs Chronic
  - Acute - little kidney involvement. Buffering via titration via Hb for example
    - pH ↓by 0.08 for 10mmHg ↑ in CO_2
  - Chronic - Renal compensation via synthesis and retention of HCO_3 (↓Cl to balance charges ➲ hypochloremia)
    - pH ↓by 0.03 for 10mmHg ↑in CO_2

Respiratory Acid-Base Disorders

- Respiratory Acidosis
  - Central - drugs (anesthetics, morphine, sedatives), stroke, infection
  - Airway - obstruction, asthma
  - Parenchyma - emphysema, pneumoconiosis, bronchitis, adult respiratory distress syndrome
  - Neuromuscular - poliomyelitis, kyphoscoliosis, myasthenia, muscular dystrophies
  - Miscellaneous - obesity, hypoventilation

Compensation:

Respiratory acidosis: Acute respiratory acidosis

HCO_3 ↑ 1 mEq/L per 10 mmHg ↑ PCO_2

Chronic respiratory acidosis

HCO_3 ↑ 4 mEq/L per 10 mmHg ↑ PCO_2

Respiratory Alkalosis

- ↑PH, ↓PCO_2, ↑Ventilation
- ↓ CO_2 ➲ ↓ HCO_3 (↑Cl to balance charges ➲ hyperchloremia)
- Causes
  - Intracerebral hemorrhage
  - Salicylate and Progesterone drug usage
  - Anxiety ➲ ↓lung compliance
  - Cirrhosis of the liver
  - Sepsis

Respiratory Alkalosis

- Acute vs. Chronic
  - Acute - ↓HCO_3 by 2 mEq/L for every 10mmHg ↓ in PCO_2
  - Chronic - Ratio increases to 4 mEq/L of HCO_3 for every 10mmHg ↓ in PCO_2

Respiratory Acid-Base Disorders

- Alkalosis
  - Central nervous system lesions, pregnancy, endotoxemia, salicylates, hepatic failure, hypoxemia, anxiety, pain

Compensation:

Respiratory alkalosis:

Acute resp alkalosis

HCO_3 ↓ 2 mEq/L per 10 mmHg ↓ PCO_2

Chronic resp acidosis

HCO_3 ↓ 5 mEq/L per 10 mmHg↓ PCO_2

Metabolic Alkalosis

- ↑PH, ↑HCO_3
- ↑PCO_2 by 0.7 for every 1mEq/L ↑ in HCO_3
- Causes
  - Vomiting
  - Diuretics
  - Chronic diarrhea
  - Hypokalemia

Metabolic Acidosis

- ↓PH, ↓HCO_3
- 12-24 hours for complete activation of respiratory compensation
- ↓PCO_2 by 1.2mmHg for every 1 mEq/L ↓HCO_3
- The degree of compensation is assessed via the Winter's Formula
  - ➲ $PCO_2 = 1.5(HCO_3) + 8 \pm 2$

Classification of Metabolic Acidosis

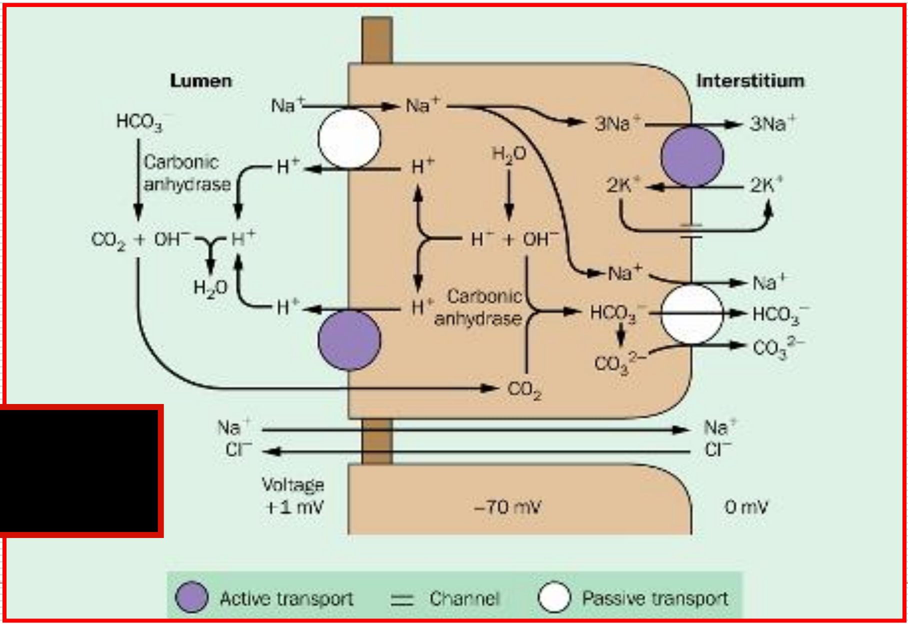
- High AG Acidosis
  - Lactic acidosis
  - Diabetic ketoacidosis
  - Starvation ketoacidosis
  - Alcoholic ketoacidosis
  - Uremic acidosis
  - Poisoning
    - Methanol
    - Ehylene Glycol
    - Salicylate
- Normal AG Acidosis
  - Hyperalimentation
  - Acetazolamide
  - RTA (Calculate urine anion gap)
  - Diarrhea
  - Pancreatic Fistula

Hyperchloremic Acidosis (Normal Anion Gap)

- Gastrointestinal Bicarbonate Loss
  - Diarrhea
- Renal Acidification Defects – Renal tubular acidosis (RTA)
  - Proximal, classical distal RTA, and hyperkalemic distal RTA
  - Early chronic renal failure

Understanding Normal Acid-Base Handling

- The Kidney
  - Reabsorbs 4500 mEq of HCO_3 per day
  - Generates new HCO_3 to replenish buffer stores
  - The Proximal tubule does most of the work
    - Luminal membrane carbonic anhydrase



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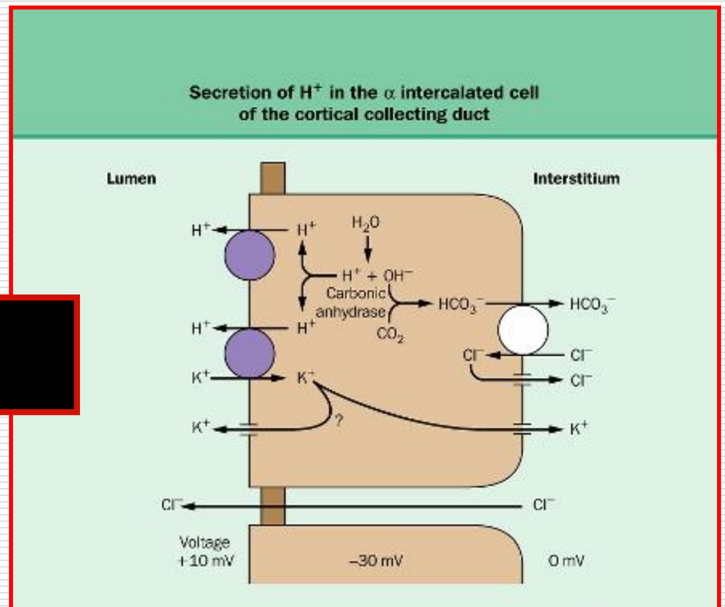
Understanding Normal Acid-Base Handling

- The Kidney
  - The Distal tubule reclaims the remainder of the HCO_3
    - Uses cytoplasmic carbonic anhydrase
    - Also eliminates H^+ = to the nonvolatile acid production



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Evaluating a Low Serum HCO3

- Renal Tubular Acidosis
  - Impaired ammonium excretion can be demonstrated by the urine net negative charge (anion gap):

    urine Na^+ + urine K^+ + urine NH_4^+ = urine Cl^-

    $$U_{Na^+} + U_{K^+} - U_{Cl^-} = -U_{NH_4^+}$$

  - Normally: $U_{Na^+} + U_{K^+} - U_{Cl^-} = -U_{NH_4^+} = < -20$ in the face of acidemia
  - In RTA's ammonium excretion is impaired, therefore

    In RTA's: $U_{Na^+} + U_{K^+} - U_{Cl^-} = -U_{NH_4^+} = 0$

    (range +20 to −80)

Urine anion gap (UAG)

Urine anion gap (UAG) in evaluation of metabolic acidosis

Positive UAG

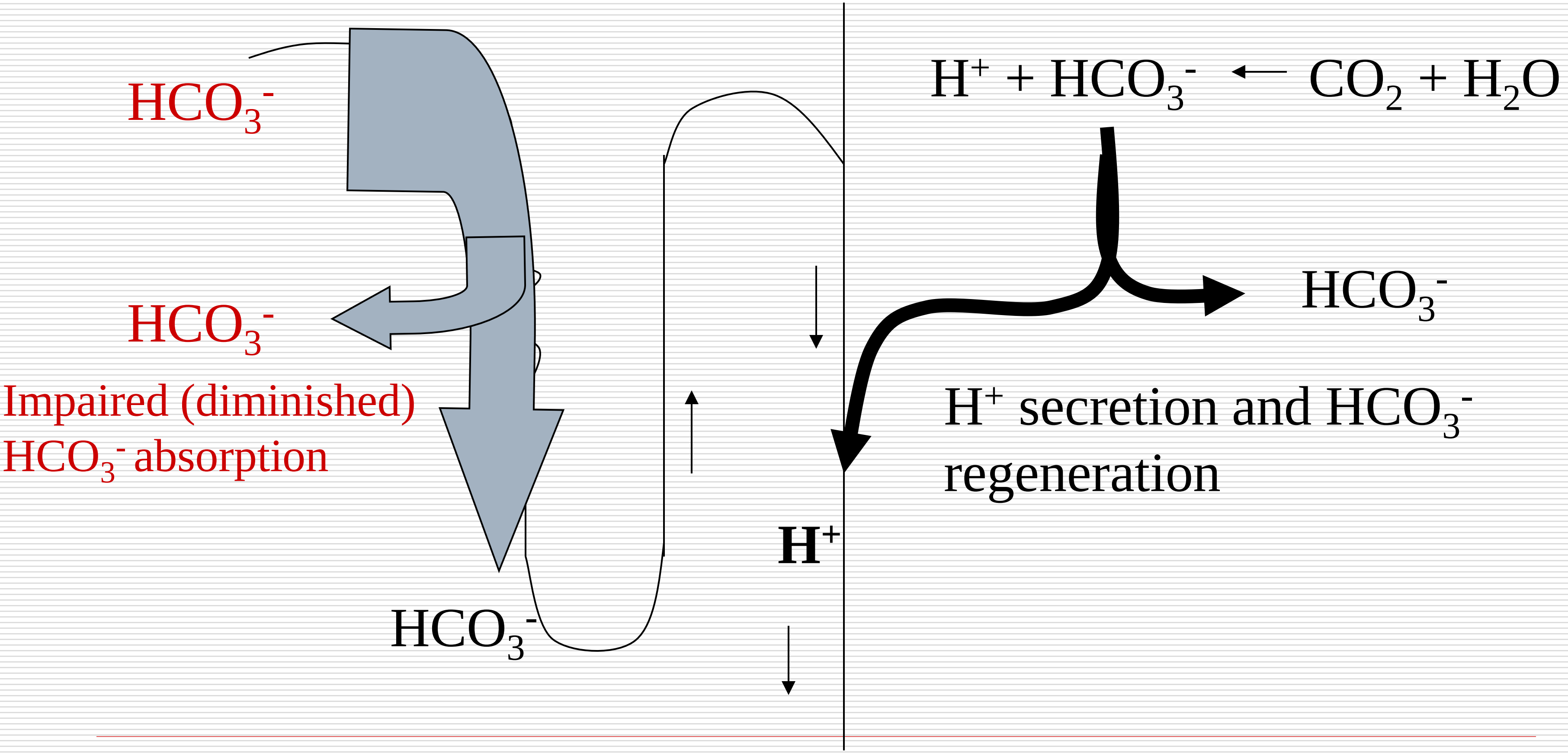
- Decreased renal ammonia production
  - Proximal renal tubular acidosis (type II)
  - Hypokalemic distal renal tubular acidosis (type I)
  - Hyperkalemic distal renal tubular acidosis (type IV)
  - Renal tubular acidosis of renal insufficiency
- Increased renal ammonia production and increased urinary excretion of sodium salts of acid
  - Sodium ketoacid salts (diabetic and alcoholic ketoacidosis)
  - Sodium hippurate and sodium benzoate (toluene poisoning)

Negative UAG

- Increased ammonia production
  - Extrarenal acidosis

Proximal Renal Tubular Acidosis

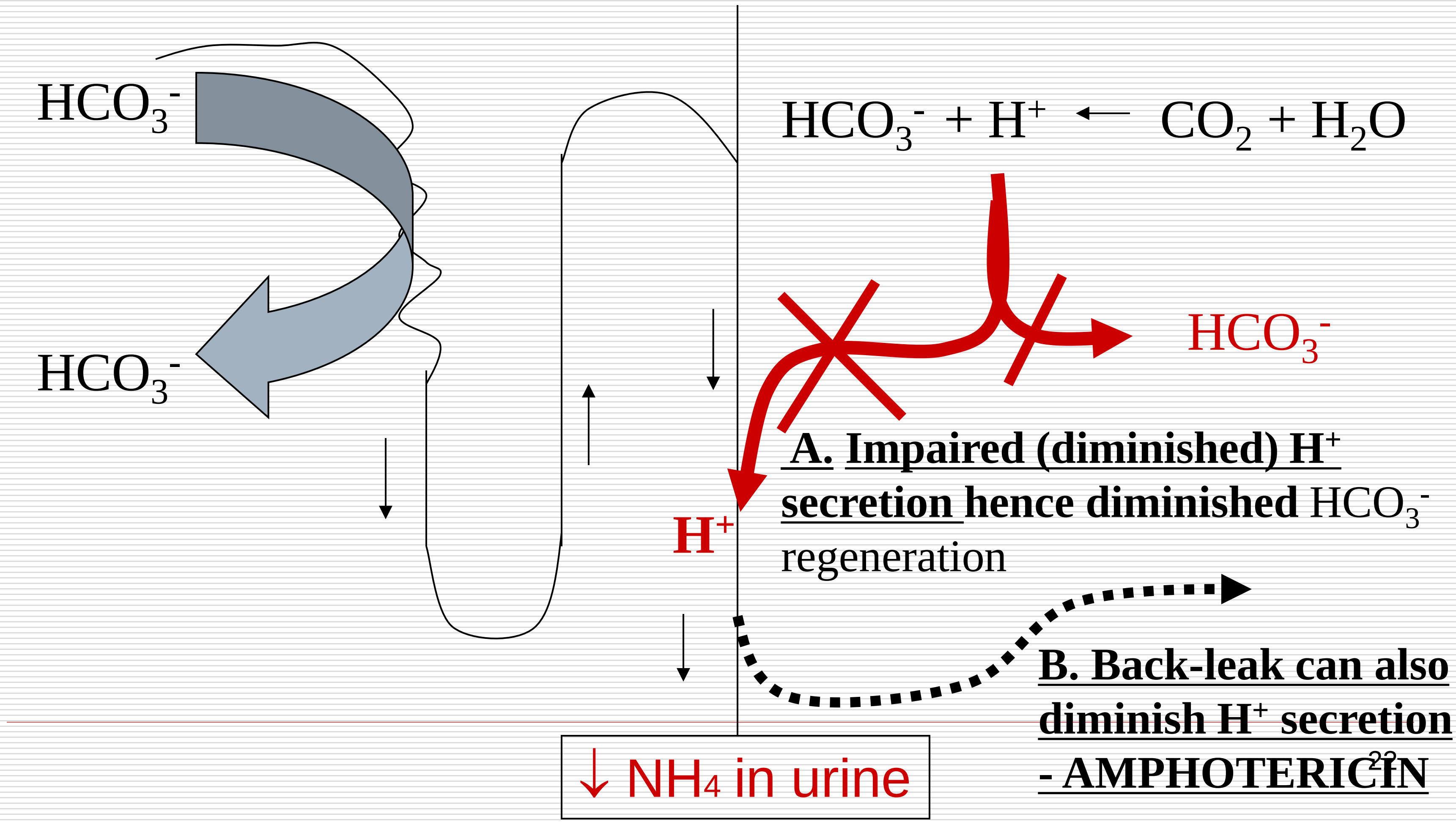
Proximal tubule | Distal Nephron / Collecting Duct



Distal Renal Tubular Acidosis

Proximal tubule | Distal Nephron / Collecting Duct

H^+ secretion and HCO_3^- regeneration



Distal RTA's

- **Impaired (diminished) H^+ secretion by the distal nephron (CCT) will result in either:**

  - Classic Distal RTA:
    Direct impairment of **H^+** ion secretion or from **H^+** backleak

  - Hyporeninemic Hypoaldosteronemic RTA (Type IV RTA):
    Inadequate aldosterone effect

Mixed Acid-Base Disorders

- Patients may have two or more acid-base disorders at one time
- Delta AG vs Delta HCO_3
- Simple high AG meta acidosis
  - Delta HCO_3 = Delta AG
- Delta HCO_3 > Delta AG
  - Combine non AG acidosis
- Delta HCO_3 < Delta AG
  - Combine meta. alkalosis

Acid - Base Status

- **Important**
- Single acid-base disturbances do not compensate to normal pH.
- A normal pH wth abnormal PaCO2 and/or HCO3- indicates two or more primary disorders.

Arterial Blood Gas (ABG) Analysis

- ABG interpretation

  Follow rules and you will always be right !!

  1) determine PH

  acidemia or alkalemia

  2) calculate the anion gap

  3) determine CO_2 compensation (winters formula)

  4) calculate the delta gap (delta HCO_3)

ABG analysis

- Arterial Blood Gas (ABG) –interpretation
  - Always evaluate PH first
    - Alkalosis – PH > 7.45
    - Acidosis – PH < 7.35
  - Determine anion gap (AG) – AG = NA – (HCO3+ CL)
    - AG metabolic acidosis
    - Non AG acidosis – determined by delta gap
  - Winters formula
    - Calculates expected PaCO2 for metabolic acidosis
    - PaCO2 = 1.5 x HCO3 + 8
  - Delta gap
    - Combine meta. Acidosis or alkalosis or not

ABG analysis

- Delta gap
  - Delta HCO3 > Delta AG : combine non AG acidosis
  - Delta HCO3 < Delta AG : combine metabolic alkalosis

  - Note: The key to ABG interpretation is following the above steps in order.

ABG **analysis**

- 33 y/o with DKA presents with the following:
  - Na = 128, Cl = 90, HCO3 = 4, Glucose = 800
  - PH 7.0/PCO_2 14/PO_2 90/HCO3- 4/Sat 95%
  - PH = acidemia
  - AG = 128 – (90 + 4) = 34
  - Winters formula – 1.5(4) + 8 = 14
  - Delta AG = 34 – 12 = 22

    Delta HCO3 = 24 – 4 = 20

    Delta HCO3 = Delta AG

ABG analysis

- Answer
  - AG acidosis with appropriate respiratory compensation
  - History c/w ketoacidosis secondary to DKA with appropriate respiratory compensation

35-year-old man admitted to the hospital with pneumonia and the following lab values:

ARTERIAL BLOOD GASES	SERUM ELECTROLYTES
pH 7.52	Na + 145 mEq/L
$PaCO_2$ 30 mm Hg	K^+ 2.9 mEq/L
PaO_2 62 mm Hg	Cl- 98 mEq/L
	HCO_3^- 22 mEq/L

Does the patient have an Alkalosis or Acidosis?

Alkalemia, pH is ↑

Is it respiratory or metabolic?

Respiratory: the $PaCO_2$ is low as is the HCO_3

Is the disorder compensated or not?

The answer:

35-year-old man admitted to the hospital with pneumonia and the following lab values:

ARTERIAL BLOOD GASES	SERUM ELECTROLYTES
pH 7.52	Na + 145 mEq/L
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	HCO_3^- 22 mEq/L

Does the patient have an Alkalosis or Acidosis?

Alkalemia, pH is ↑

Is it respiratory or metabolic?

Respiratory: the $PaCO_2$ is low as is the HCO_3

Is the disorder compensated or not?

Yes, the predicted HCO_3 is 22 mEq/L

How do we know what the HCO_3 should be?
Remember, the HCO_3 will ↓ 2 mEq/L for every 10 mmHg the $PaCO_2$ ↓ as acute compensation.

The answer: Compensated Respiratory Alkalosis

68-year-old man with emphysema

Arterial blood gas	Serum Electrolytes	
pH 7.34	Na^+	138
$PaCO_2$ 70 mm Hg	K^+	4.7
	Cl^-	91
	HCO_3^-	36

Does the patient have an acidosis or alkalosis? Acidemia

Is it metabolic or respiratory? Respiratory

Is the respiratory acidosis compensated for? Yes, the HCO_3 should be 36 mEq/L

Remember the HCO_3 will ↑ 4 mEq/L for every 10 mm Hg ↑ the $PaCO_2$ in chronic respiratory acidosis.
In this case the $PaCO_2$ ↑by 30 mmHg thus the HCO_3 ↑ by 12 mEq/L
In acute respiratory acidosis the HCO_3 will ↑1 mEq/L.

The answer: Compensated Respiratory Acidosis

What is (are) the acid-base disorder(s) evident in the following values, from a 27-year-old woman with acute renal failure?

Arterial Blood Gas	Serum Electrolytes
pH 7.32	Na+ 144 mEq/L
PaCO2 23 mm Hg	K+ 4 mEq/L
	Cl - 108 mEq/L
	HCO3- 10 mEq/L

Does the patient have an acidosis or alkalosis? — Acidemia

Is it metabolic or respiratory? — Metabolic

Now that we have determined a metabolic acidosis, is the anion gap normal or elevated? — High Anion Gap at 26

Remember the anion gap = Na - (HCO_3 + Cl) and normal is 12

Now that we have determined a high anion gap what made the anion gap go up? — The drop in HCO_3

So does the drop in HCO_3 equal the increase in the anion gap? — Yes, the Δ HCO_3 (14) = the Δ Anion gap (14)

Is the respiratory compensation adequate? — Yes, the $PaCO_2$ should be 23 mmHg

Use Winter's Formula to predict the $PaCO_2$ with a metabolic acidosis: 1.5 (HCO_3) + 8 ($\pm$2)

The answer: Compensated High Anion Gap Metabolic Acidosis

55-year-old-man seen for newly diagnosed renal failure

Arterial blood gas	Serum chemistries			
pH 7.38	Na^+	140	Cr	1.9
$PaCO_2$ 30	K^+	3.2	HGB	8.0
	Cl^-	115		
	HCO_3^-	14		

Does the patient have an acidosis or alkalosis?

Acidemia

Is it metabolic or respiratory?

Metabolic

Now that we determined a metabolic acidosis what do we check next?

The anion gap

The anion gap = 11

Remember the anion gap = Na - (HCO_3 + Cl) and normal is 12

Thus this is a normal anion gap acidosis or a hyperchloremic acidosis, notice the Chloride is 115 mEq/L.

Is the metabolic acidosis compensated?

Yes, the $PaCO_2$ should be 29

Remember Winter's Formula, 1.5 (HCO_3) +8 ($\pm$2)

The answer: Compensated Hyperchloremic Metabolic Acidosis

Q1. 27-year-old woman with acute renal failure

Arterial blood gas	Serum electrolytes	
pH 7.12	Na+	140
PaCO2 13 mm Hg	K+	4.0
	Cl-	115
	HCO3-	5

Does the patient have an acidosis or alkalosis? — Acidemia

Is it metabolic or respiratory? — Metabolic

So, what is the anion gap? — Anion gap = 20

Is the Δ anion gap = to the Δ HCO_3? — NO, Δ anion gap = 8, Δ HCO_3 = 19

Thus the Δ HCO_3 > the Δ anion gap, this means the HCO_3 went down more than the anion gap went up.

Something made the HCO_3 drop further, the two disorders that decrease the HCO_3 even further are:

Hyperchloremic metabolic acidosis or compensation for a respiratory alkalosis.

Is the respiratory compensation adequate? — Yes, the predicted $PaCO_2$ = 15 mmHg

The Answer: Compensated High Anion Gap Metabolic Acidosis with a Hyperchloremic Metabolic Acidosis

Q2: 19yo college student was found by roommate on floor. Diaphoretic and comatose

Arterial blood gas	Serum electrolytes		
pH 7.42	Na^+	152	BUN 30
$PaCO_2$ 24 mm Hg	K^+	3.6	Cr 1.0
PaO_2 115 mmHg	Cl^-	104	
	HCO_3^-	15	

Does the patient have an acidosis or alkalosis?

Don’t know the pH is normal

So, where do we start?

A good place to start is the anion gap

The anion gap = 33

Thus there is at least a high anion gap metabolic acidosis

So, now what?

Check the Δ HCO_3 and Δ anion gap

The Δ HCO_3 = 24 - 15 = 9
The Δ anion gap = 33 - 12 = 21
Thus they are not equal

So, what does this mean?

The anion gap went up more than the HCO_3 went down. Thus there is something keeping the HCO_3 up.

Q2: 19yo college student was found by roommate on floor. Diaphoretic and comatose

Arterial blood gas	Serum electrolytes		
pH 7.42	Na^+	152	BUN 30
$PaCO_2$ 24 mm Hg	K^+	3.6	Cr 1.0
PaO_2 115 mmHg	Cl^-	104	
	HCO_3^-	15	

So, we determined the Δ anion gap > Δ HCO_3

This suggest there is either a Metabolic alkalosis or a Respiratory acidosis with compensation, both will cause the HCO_3 to be high

So, check Winter's formula to determine the respiratory compensation. [1.5 (HCO_3) + 8]

The predicted $PaCO_2$ is 30
This is higher than the measured $PaCO_2$, thus the patient has a respiratory alkalosis

The answer: High anion gap met acidosis with met alkalosis with resp alkalosis