Acid-Base Imbalance-2

Lecture 9 (12/4/2015)

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$$pH = pK + \log \frac{[HCO_3]}{[H_2CO_3]}$$

Introduction

- **Disturbance in acid-base balance are common clinical problem that range in severity from mild to life threatening, the acute toxicity of acid-base derangements will primarily involve the heart and the brain, the four primary acid-base disorder's:**
  - **Metabolic acidosis**
  - **Metabolic Alkalosis**
  - **Respiratory acidosis**
  - **Respiratory alkalosis**
  - **Mixed acid-base disorders.**

Acid-Base Imbalance

1. Many conditions that cause a disturbance in the body pH such as vomiting and diarrhea are dominated clinically by abnormalities in fluid and electrolyte balance and it is the dehydration rather than the pH change that required immediate attention rather than acid base correction.
2. The same apply for hypocalcaemia where ensuring proper hydration rather than trying to correct the serum calcium. Similarity adequate fluid and electrolyte replacement will permit correction of any associated pH abnormality in the majority of patients.
3. However, there are occasions when the pH disorder dominates the clinical picture and it is necessary to administer base or less commonly acid, these include the acute acidosis: server hypovolemic shock, diabetic ketoacidosis, cardiac arrest and the acute Alkalosis of alkali over dose, pyloric stenosis etc.

Classification of Acid-Base Disorders from plasma pH, pCO_2, and HCO_3^-

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

Acidosis : pH < 7.4

- metabolic : ↓ HCO_3^-
- respiratory : ↑ pCO_2

Alkalosis : pH > 7.4

- metabolic : ↑ HCO_3^-
- respiratory : ↓ pCO_2

pH Disturbances:

- Acidosis is more common than alkalosis.
- metabolic acidosis is more common than respiratory acidosis.
- Most common cause of M acidosis is diarrhea. (loosing HCO3-).
- Diarrhea treatment include: rehydration,
- electrolyte imbalance, and pH correction

pH disturbance:

Metabolic → HCO_3

Respiratory → **PCO2**

	pH	P_aCO_2	HCO_3^-
M. Acidosis	↓	↓	↓
M. Alkalosis	↑	↑	↑
R. Acidosis	↓	↑	↑
R. alkalosis	↑	↓	↓

Classification of Acid-Base Disturbances

	Plasma			
Disturbance	pH	HCO_3^-	pCO_2	Compensation
metabolic acidosis	↓	↓	↓	↑ ventilation ↑ renal HCO_3 production
respiratory acidosis	↓	↑	↑	↑ renal HCO_3 production
metabolic alkalosis	↑	↑	↑	↓ ventilation ↑ renal HCO_3 excretion
respiratory alkalosis	↑	↓	↓	↑ renal HCO_3 excretion

Simple Versus Mixed `Acid-Base Imbalance

- **Mixed (complex) disorder** **(either term can be used).**

•*M. Acidosis	**For every ↓ 1 mEq HCO_3^- → 1.2 mm Hg PCO2 ↓ too.**
•M. Alkalosis**	**For every 1 mEq↑ in HCO3-→ 0.7 mmHg ↑ in PCO2**
•*R. Acidosis**	
•Acute:	**For every 10 mmHg ↑ in PCO2 → 1 mEq ↑ in HCO_3^-**
•Chronic	**For every 10 mmHg ↑ in PCO2 → 3.5 mEq↑ in HCO_3^-**
•**R. Alkalosis**	
•Acute	**For every 10 mmHg ↓ PCO2 → 2 mEq ↓ HCO_3^-**
•Chronic	**For every 10 mmHg ↓ PCO2 → 5 mEq ↓ HCO_3^-**

- * if PCO_2 ↓ more than expected→ superimposed R. alkalosis too.
- * if PCO_2 ↓ less than expected→ superimposed R. acidosis too.
- ** if PCO_2 ↑ more than expected→ superimposed R. acidosis too.
- ** if PCO_2 ↑ less than expected→ superimposed R. alkalosis too.
- *** if HCO_3 ↑ more than expected→ superimposed M. alkalosis too.
- *** if HCO_3 ↑ less than expected→ superimposed M. acidosis too.
- **** if HCO_3 ↓ more than expected→ superimposed M. acidosis too.
- **** if HCO_3 ↓ less than expected→ superimposed M. alkalosis too.
- *** In metabolic acidosis respiratory system compensate more than metabolic alkalosis because acidosis induces hyperventilation while alkalosis induces hypoventilation which may be opposed by hypoxia

- Acute metabolic acidosis (not for long period of time) is not accompanied with respiratory compensation.

* Respiratory compensation starts to act after minutes, full effect after hours.

Renal Compensation for Acidosis

Increased addition of HCO_3^- to body by kidneys
(increased H^+ loss by kidneys)

Titratable acid	= 35 mmol/day (small increase)
*NH_4^+ excretion	= 165 mmol/day (increased)
HCO_3^- excretion	= 0 mmol/day (decreased)
Total	= 200 mmol/day

*This can increase to as high as 500 mmol/day

Renal Compensation for Alkalosis

Net loss of HCO_3^- from body
(i.e. decreased H^+ loss by kidneys)

Titratable acid	= 0 mmol/day (decreased)
NH_4^+ excretion	= 0 mmol/day (decreased)
HCO_3^- excretion	= 80 mmol/day (increased)
Total	= 80 mmol/day

HCO_3^- excretion can increase markedly in alkalosis

Renal Responses to Respiratory Acidosis

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

Respiratory acidosis : ↓ pH ↑ pCO_2 ↑ HCO_3^-

↑ PCO_2 → ↑ H^+ secretion → complete HCO_3^- reabs.

\+

excess tubular H^+

↓ pH

Buffers (NH_4^+, $NaHPO_4^-$) →

↑ H^+ Buffers$^-$

\+

↑ new HCO_3^-

⊖ (↑ new HCO_3^- ⇢ ↓ pH)

Renal Responses to Metabolic Acidosis

Metabolic acidosis : ↓ pH ↓ pCO_2 ↓ HCO_3^-

↓ HCO_3^- → ↓ HCO_3^- filtration → complete HCO_3^- reabs.

\+

excess tubular H^+

↓ pH

Buffers (NH_4^+, $NaHPO_4$-) →

↑ H^+ Buffers$^-$

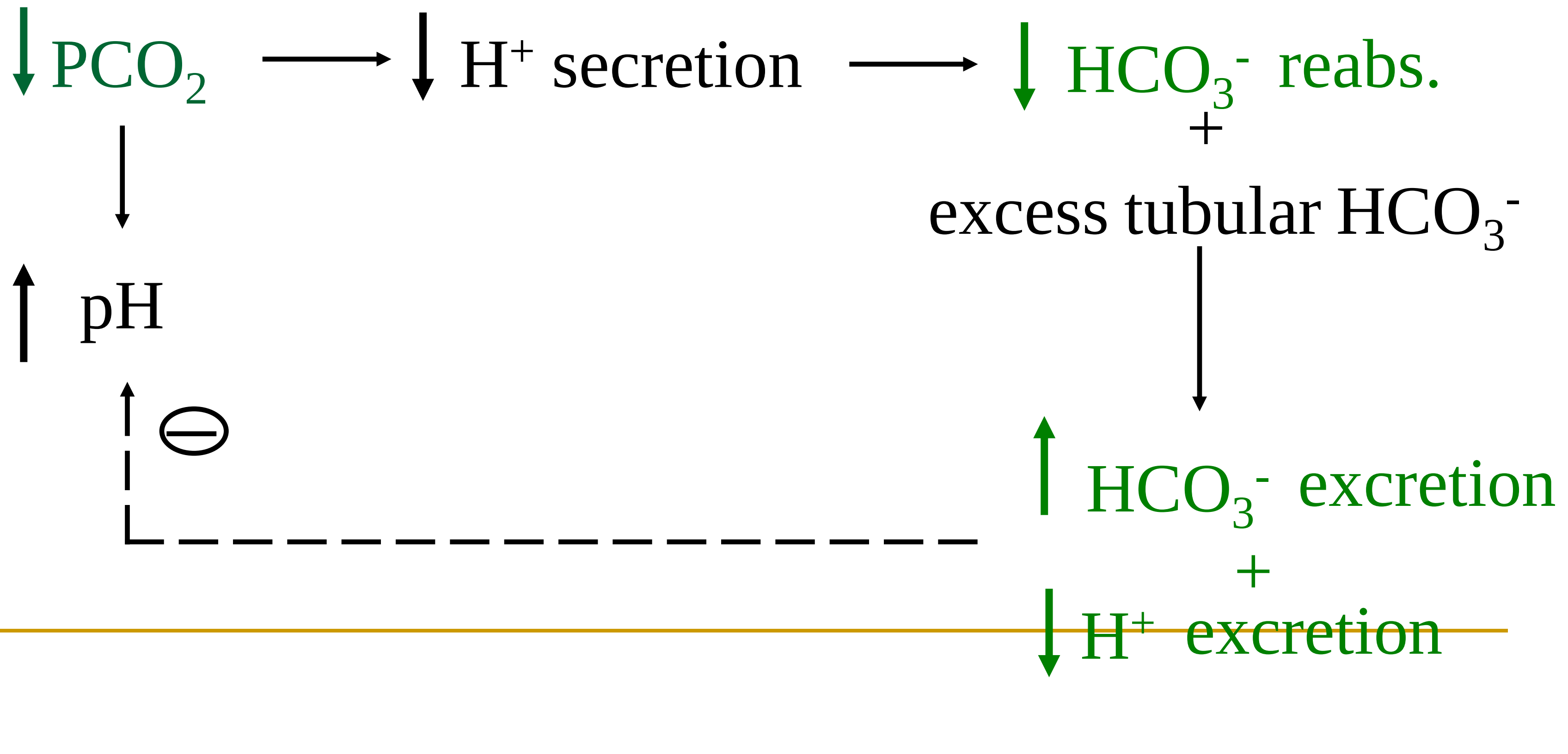
\+

↑ new HCO_3^-

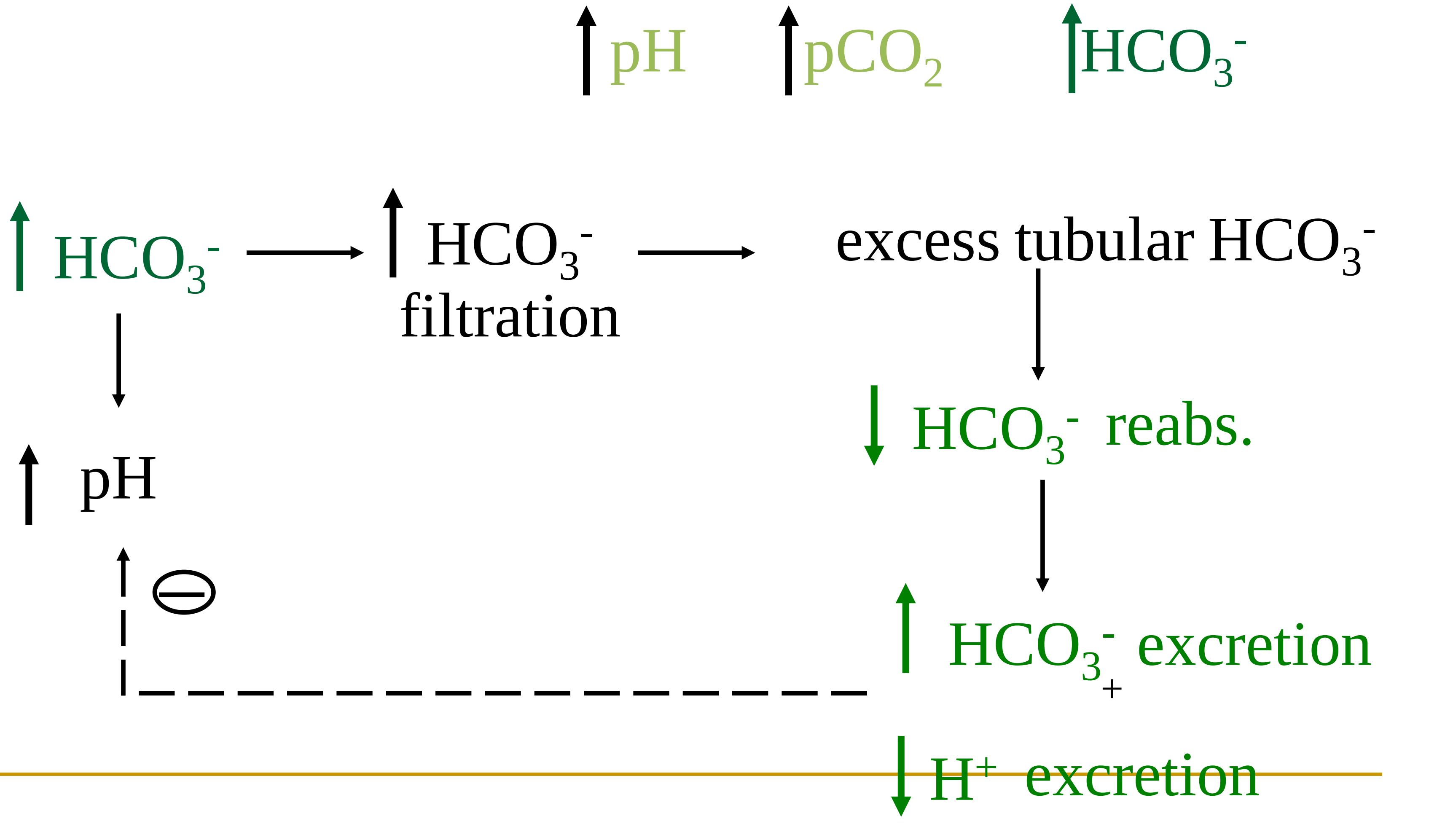
⊖

Renal Responses to Respiratory Alkalosis

Respiratory alkalosis : ↑ pH ↓ pCO_2 ↓ HCO_3^-



Renal Responses to Metabolic Alkalosis



Metabolic acidosis:

Non-respiratory acidosis is better term, but metabolic acidosis is most commonly used.

1. Renal tubular acidosis

2. ↑ HCO_3^- loss: diarrhea is the most common cause of M. acidosis, another cause is deep vomiting (pancreatic juice is full of HCO_3^-).

3. ↑ H^+ production: as in D.M, also ingestion of Aspirin or when acetoacetic acids are produced from fats.

→ Acidosis stimulate respiratory center causing hyperventilation, decreasing CO_2 as compensation.

Acid-Base Disturbances

- Metabolic Acidosis : ↓ HCO_3^- / pCO2 in plasma
  (↓pH, ↓HCO_3^-)

- aspirin poisoning (↑ H^+ intake)
- diabetes mellitus (↑H^+ production)
- diarrhea (↑ HCO_3^- loss)
- renal tubular acidosis (↓H^+ secretion, ↓HCO_3^- reabs.)
- carbonic anhydrase inhibitors (↓ H^+ secretion)

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$\downarrow pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

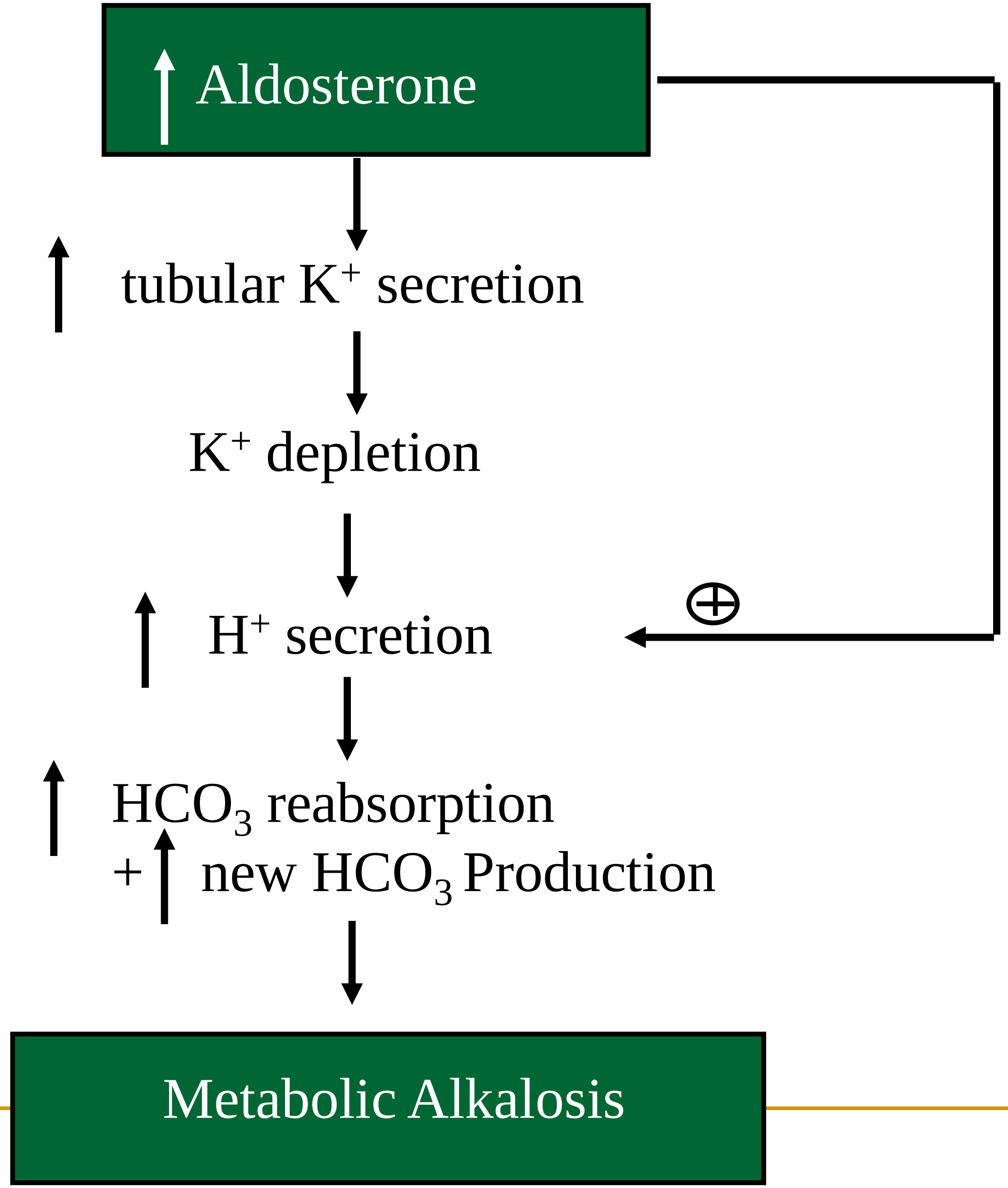
M.Alkaosis

- Metabolic Alkalosis : ↑ (HCO_3^- / pCO_2) in plasma
  (↑ pH, ↑ HCO_3^-)

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$\uparrow pH = pK + \log \frac{HCO_3^-}{\alpha \ pCO_2}$$

- **Metabolic Alkalosis:**
- “not common”
- 1. Diuretics with the exception of C.A inhibitors :↑ flow → ↑ Na+ reabsorption → ↑ H+ secretion.
- 2. ↑ aldostrerone.
- 3. Vomiting of gastric content only (Pyloric stenosis)
- 4. Administration of $NaHCO_3$.

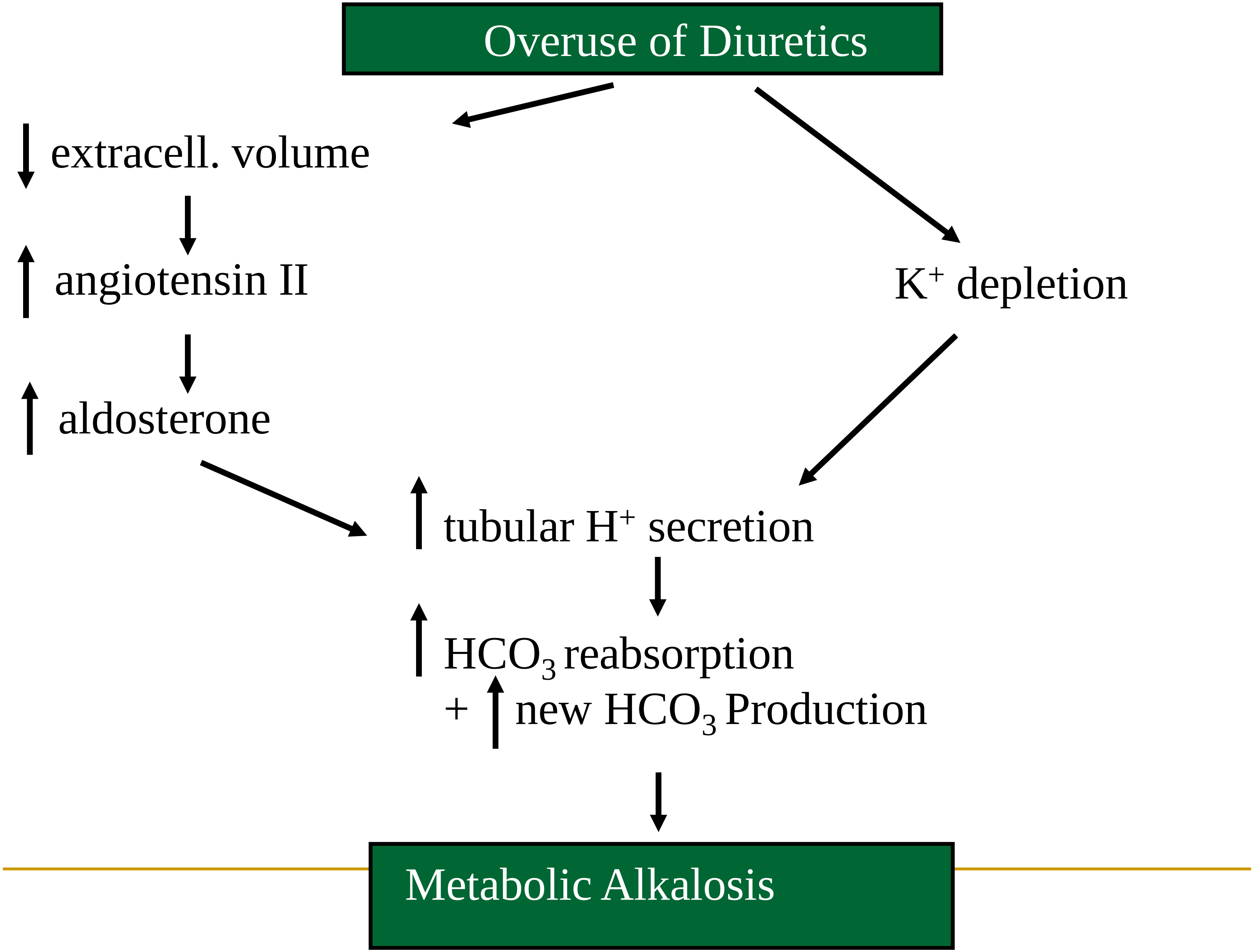


↑ Aldosterone
↑ tubular K+ secretion
K+ depletion
↑ H+ secretion
⊕
↑ HCO3 reabsorption
+ ↑ new HCO3 Production
Metabolic Alkalosis

- **Respiratory Acidosis** : ↓ in the fraction ↓(HCO_3^- / PCO_2) in pla
  (↓ pH, ↑pCO_2)

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$\downarrow pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$


Overuse of Diuretics
↓ extracell. volume
↑ angiotensin II
↑ aldosterone
K⁺ depletion
↑ tubular H⁺ secretion
↑ HCO3 reabsorption
+ ↑ new HCO3 Production
Metabolic Alkalosis

Respiratory acidosis:

Respiratory here does not mean the lung: it means CO_2

→ (as in hemodialysis). → pH decreases due to increase in CO_2 concentration.

causes:

1. Gas exchange (↓ Ability of the lung to eliminate CO_2 such as): pneumomia , lack of lung tissue, airway obstruction, ↓ surface area.

2. CNS damage to the respiratory CNTR. trauma , tumors.

3. Respiratory muscles: phrenic paralysis, diaphragmatic fatigue

R. Alkalosis

- Respiratory Alkalosis : ↑ HCO_3^- / pCO2 in plasma
  (↑ pH, ↓ pCO_2)

  - high altitude
  - psychic (fear, pain, etc)

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

$$\uparrow pH = pK + \log \frac{HCO_3^-}{\alpha \ pCO_2}$$

Question

The following data were taken from a patient:

urine volume = 1.0 liter/day
urine HCO_3^- concentration = 2 mmol/liter
urine NH_4^+ concentration = 15 mmol/liter
urine titratable acid = 10 mmol/liter

- What is the daily net acid excretion in this patient ?
- What is the daily net rate of HCO_3^- addition to the extracellular fluids ?

Answer

The following data were taken from a patient:

urine volume = 1.0 liter/day

urine HCO_3^- concentration = 2 mmol/liter

urine NH_4^+ concentration = 15 mmol/liter

urine titratable acid = 10 mmol/liter

net acid excretion = Titr. Acid + NH_4^+ excret - HCO_3^-

= (10 x 1) + (15 x 1) - (1 x 2)

= 23 mmol/day

net rate of HCO_3^- addition to body = 23 mmol/day

Question

A plasma sample revealed the following values in a patient:

$pH = 7.12$

$PCO_2 = 50$

$HCO_3^- = 18$

diagnose this patient's acid-base status :

acidotic or alkalotic ?

respiratory, metabolic, or both ?

Acidotic

Both

Mixed acidosis: metabolic and respiratory acidosis

MIXED pH DISTURBANC

1. Metabolic acidosis plus respiratory acidosis:

Cardio pulmonary arrest
COPD goes in shock

2. Metabolic Alkalosis plus respiratory alkalosis:.

- Head trauma leads to hyperventilation in patient with diuretics.

3. Metabolic acidosis plus respiratory alkalosis lactic acidosis complicating septic shock.

4. Metabolic Alkalosis plus respiratory acidosis (COPD) who is vomiting or treated with N.G suction or potent diuretics

Examples for Mixed Acid-Base Disturbances

Two or more underlying causes of acid-base disorder.

pH= 7.60
pCO_2 = 30 mmHg
plasma HCO_3^- = 29 mmol/L

What is the diagnosis?

Mixed Alkalosis

- Metabolic alkalosis : increased HCO_3^-
- Respiratory alkalosis : decreased pCO_2

Question

A patient presents in the emergency room and the following data are obtained from the clinical labs:

plasma pH= 7.15, HCO_3^- = 8 mmol/L, pCO_2= 24 mmHg

This patient is in a state of:

1. metabolic alkalosis with partial respiratory compensation
2. respiratory alkalosis with partial renal compensation
3. metabolic acidosis with partial respiratory compensation
4. respiratory acidosis with partial renal compensation

Anion Gap as a Diagnostic Tool

In body fluids: total cations = total anions

Cations (mEq/L)		Anions (mEq/L)	
Na^+	(142)	Cl^-	(108)
		HCO_3^-	(24)
		Unmeasured	
K^+	(4)	Proteins	(17)
Ca^{++}	(5)	Phosphate,	
Mg^{++}	(2)	Sulfate,	
		lactate, etc	(4)
Total	(153)		(153)

Anion Gap as a Diagnostic Tool

$Na^+ = Cl^- + HCO_3^-$ + unmeasured anions

unmeasured anions = $Na^+ - Cl^- - HCO_3^-$ = anion gap

= 142 - 108 - 24 = 10 mEq/L

Normal anion gap = 8 - 16 mEq / L

Anion Gap in Metabolic Acidosis

- ↑unmeasured anions = ↑anion gap
- loss of HCO_3^- and Na+= normal anion gap

normal anion gap = Na^+ - ↑Cl^- - ↓ HCO_3^-

hyperchloremic metabolic acidosis

↑anion gap = Na^+ - Cl^- - ↓HCO_3-

normochloremic metabolic acidosis

i.e. diabetic ketoacidosis, lactic acidosis, salicylic acid, etc.

Use of "Anion Gap" as a Diagnostic Tool for Metabolic Acidosis

Increased Anion Gap (normal Cl^-)

- diabetes mellitus (ketoacidosis)
- lactic acidosis
- aspirin (acetysalicylic acid) poisoning
- methanol poisoning
- starvation

Normal Anion Gap (increased Cl^-, hyperchloremia)

- diarrhea
- renal tubular acidosis
- Addison' disease
- carbonic anhydrase inhibitors

Laboratory values for an uncontrolled diabetic patient include the following:

arterial pH = 7.25

Plasma HCO_3^- = 12

Plasma P_{CO_2} = 28

Plasma Cl^- = 102

Plasma Na^+ = 142

Metabolic Acidosis

Respiratory Compensation

What type of acid-base disorder does this patient have?

What is his anion gap ?

Anion gap = 142 - 102 -12 = 28

Which of the following are the most likely causes of his acid-base disorder?

a. diarrhea

b. diabetes mellitus

c. Renal tubular acidosis

d. primary aldosteronism

Laboratory values for a patient include the following:

arterial pH = 7.34

Plasma HCO_3^- = 15

Plasma P_{CO_2} = 29

Plasma Cl^- = 118

Plasma Na^+ = 142

Metabolic Acidosis

Respiratory Compensation

What type of acid-base disorder does this patient have?

What is his anion gap ?

Anion gap = 142 - 118 - 15 = 9 (normal)

Which of the following are the most likely causes of his acid-base disorder?

a. diarrhea
b. diabetes mellitus
c. aspirin poisoning
d. primary aldosteronism

Indicate the Acid -Base Disorders in Each of the Following Patients

pH	HCO_3^-	PCO_2	Acid-Base Disorder ?
7.34	15	29	Metabolic acidosis
7.49	35	48	Metabolic alkalosis
7.34	31	60	Respiratory acidosis
7.62	20	20	Respiratory alkalosis
7.09	15	50	Acidosis: respiratory + metabolic