ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
Εθνικόν και Καποδιστριακόν Πανεπιστήμιον Αθηνών
ΙΔΡΥΘΕΝ ΤΟ 1837

NEPHROLOGY 500461:
Homeostasis of electrolytes

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Assistant Professor of Nephrology, Aretaieio Hospital, NKUA Medical School

2025

OUTLINE

INTRODUCTION

Acid-base balance, arterial blood gases (ABGs), introduction to acid-base disorders

METABOLIC ALKALOSIS

Clinical cases

Pathogenesis - Signs and symptoms - Diagnosis

METABOLIC ACIDOSIS

Clinical cases

Pathogenesis - Signs and symptoms - Diagnosis

RESPIRATORY ALKALOSIS AND ACIDOSIS

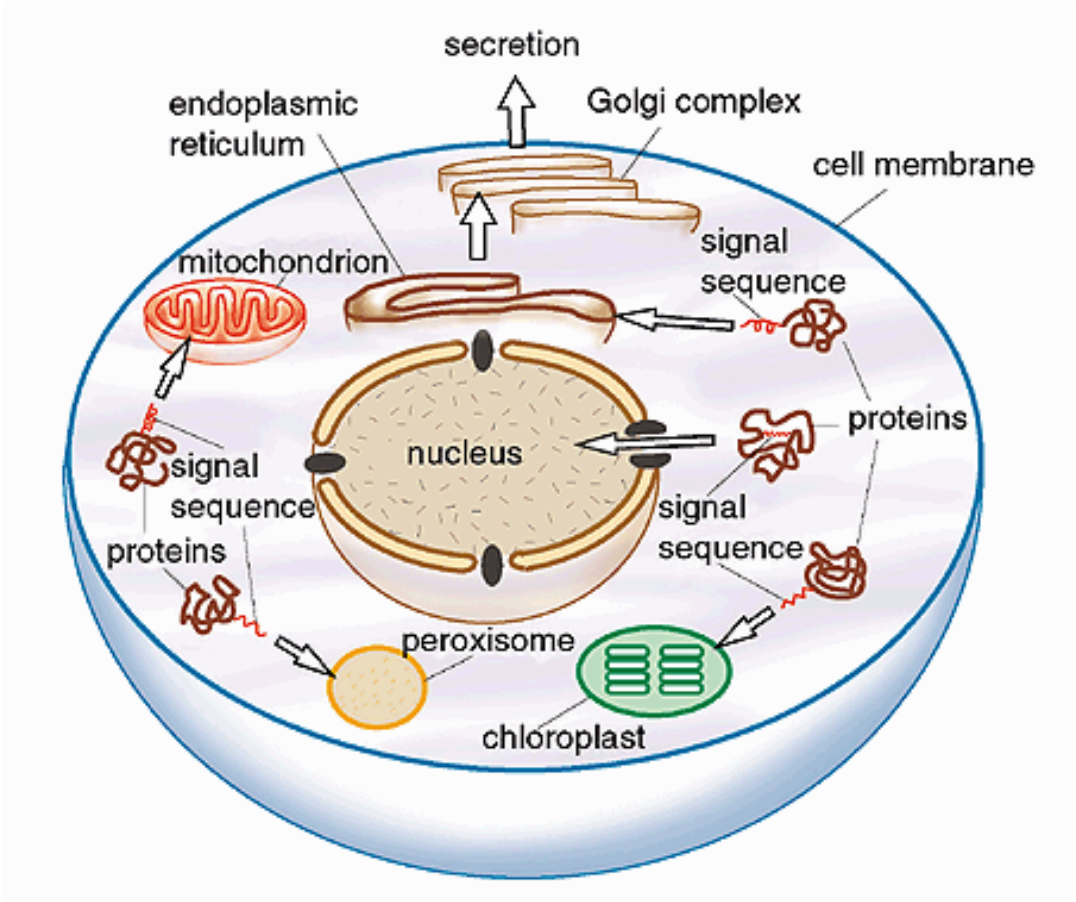
Clinical cases

Pathogenesis - Signs and symptoms - Diagnosis

Berne and Levy Physiology, ELSEVIER 2018

BD Rose and T Post. Clinical Physiology of Acid-Base and Electrolyte Disorders. McGraw Hill 2000

[H^+] IS MAINTAINED WITHIN NARROW LIMITS (40 nmol/L)



$\Delta[H^+]$

↓

Proteins gain or lose H^+

↓

Alterations in protein charge, structure and function

↓

Cellular dysfunction

https://www.nobelprize.org/nobel_prizes/medicine/laureates/1999/press.html

DAILY ACID PRODUCTION

$HA \longleftrightarrow H^+ + A^-$ *[Bronsted definition]*

CARBONIC ACID	NON-CARBONIC ACIDS
$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$	$NH_4^+ \longleftrightarrow H^+ + NH_3$
	$H_2PO_4^- \longleftrightarrow H^+ + HPO_4^{2-}$
Metabolism of carbohydrates and lipids	Metabolism of proteins
15000 mmol CO_2	1 mEq/Kg BW H^+
Loss via respiration	Excreted in urine

Carbonic acid and non-carbonic acids have
different rates of production and different routes of elimination

ACID-BASE BALANCE

maintains plasma [H^+] within narrow limits to maintain normal cellular function

1. Chemical buffering by the intracellular and extracellular **buffers**
2. Control of partial pressure of PCO_2 in the blood by altering **alveolar ventilation**
3. Control of plasma HCO_3^- concentration by changes in **renal H^+ excretion**

ACID-BASE BALANCE

1. BODY BUFFERS

- **Weak acids or bases** with their ionized salts that immediately take up or release H^+ to minimize large changes in $[H^+]$

- EXTRACELLULAR

  $H^+ + HCO_3^- \longleftrightarrow$ **H2CO3** $\longleftrightarrow H_2O + CO_2$

  $Na^+ + HCO_3^- \longleftarrow$ **$NaHCO_3$**

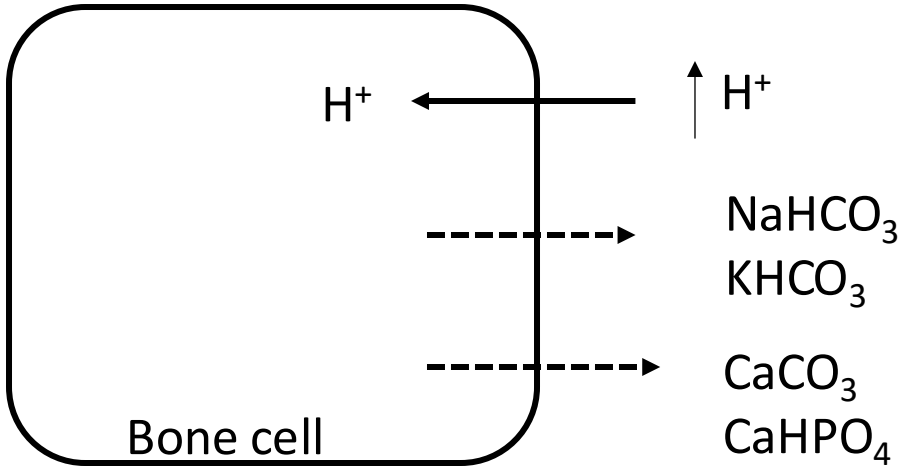
  $H^+ + Pr^- \longleftrightarrow$ **HPr** (plasma proteins)

  $H^+ + HPO_4^{2-} \longleftrightarrow$ **$H_2PO_4^-$** (phosphate ions)

- INTRACELLULAR

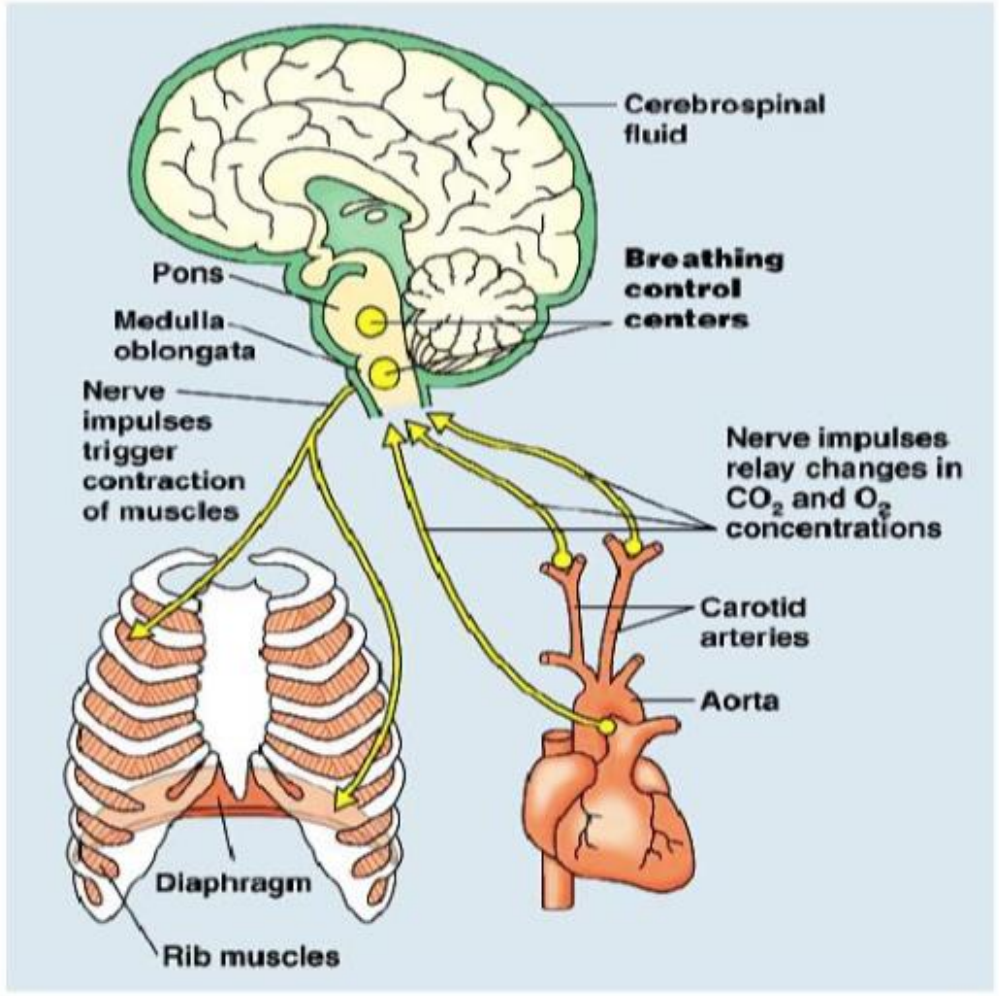
  proteins, hemoglobin, bones, skeletal muscles

  $H^+ + Hb^- \longleftrightarrow$ **HHb**



ACID-BASE BALANCE

2. ALVEOLAR VENTILATION



↓pH

↓

Peripheral chemoreceptors

(carotid bodies)

↓

Respiratory Centre

↓

↑Respiratory rate

↓

↓PCO_2

↓

↑pH

ACID-BASE BALANCE

3. RENAL H^+ SECRETION

- Kidneys must excrete the 1 mEq/kg BW of non-carbonic acid **generated each day**

- Daily acid load cannot be excreted as free H^+ ions

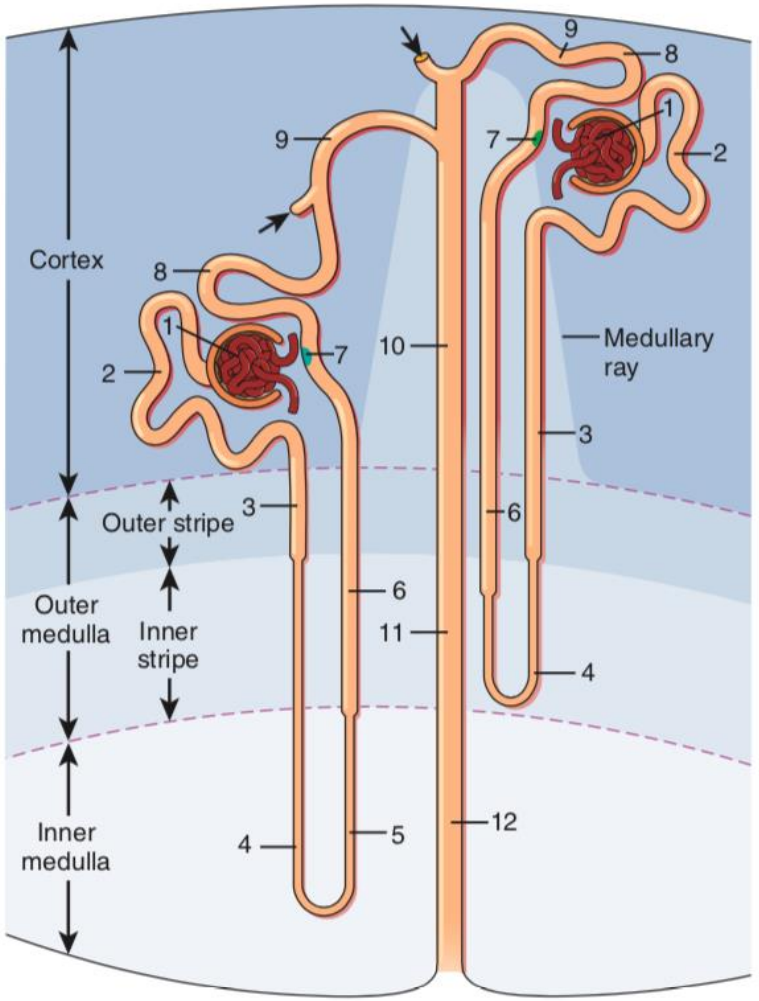
  Secreted H^+ are excreted by binding to buffers, such as HPO_4^{2-}, creatinine and NH_3

- Daily acid load cannot be excreted unless **all filtered $HCO3^-$ have been reabsorbed**

  ($HCO3^-$ loss in urine = H^+ addition to the blood)

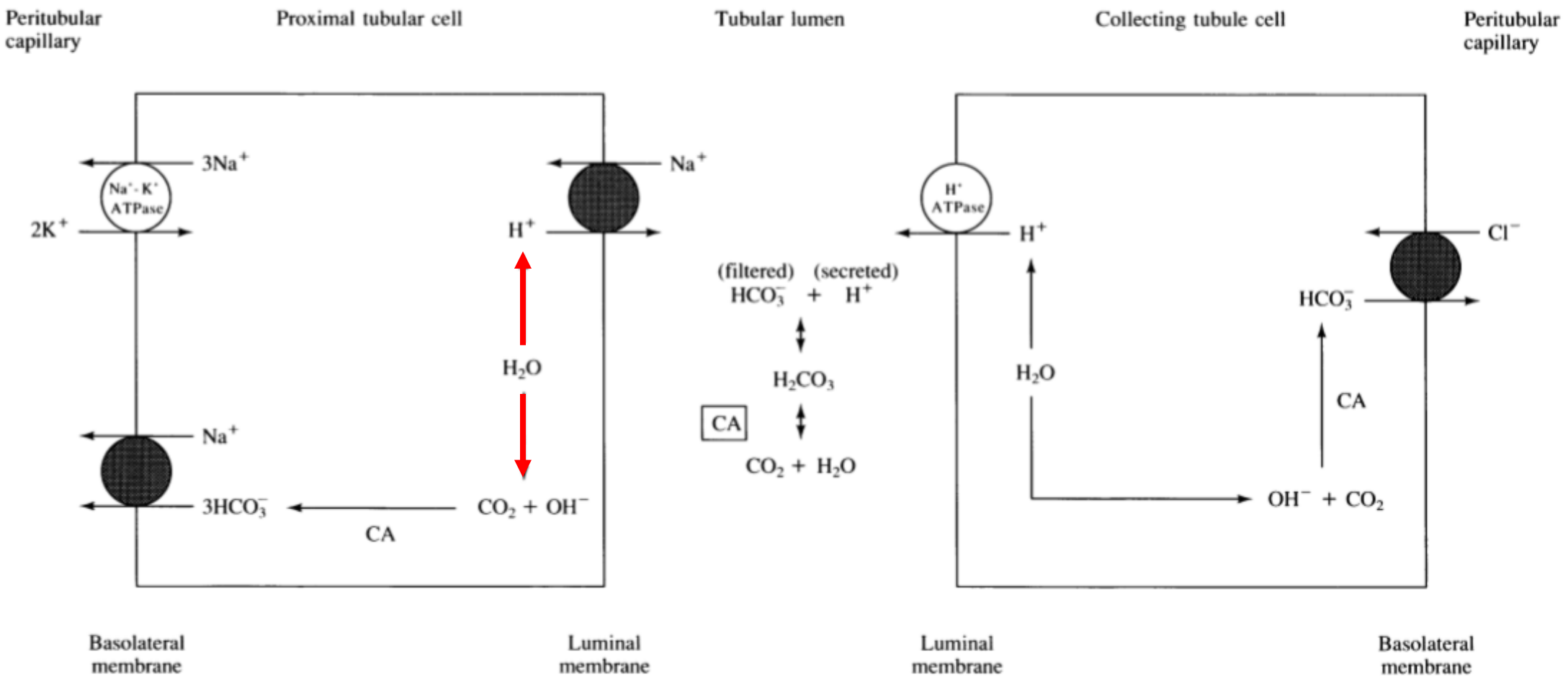
ACID-BASE BALANCE

3. RENAL H^+ SECRETION



ACID-BASE BALANCE

3a. RENAL H^+ SECRETION



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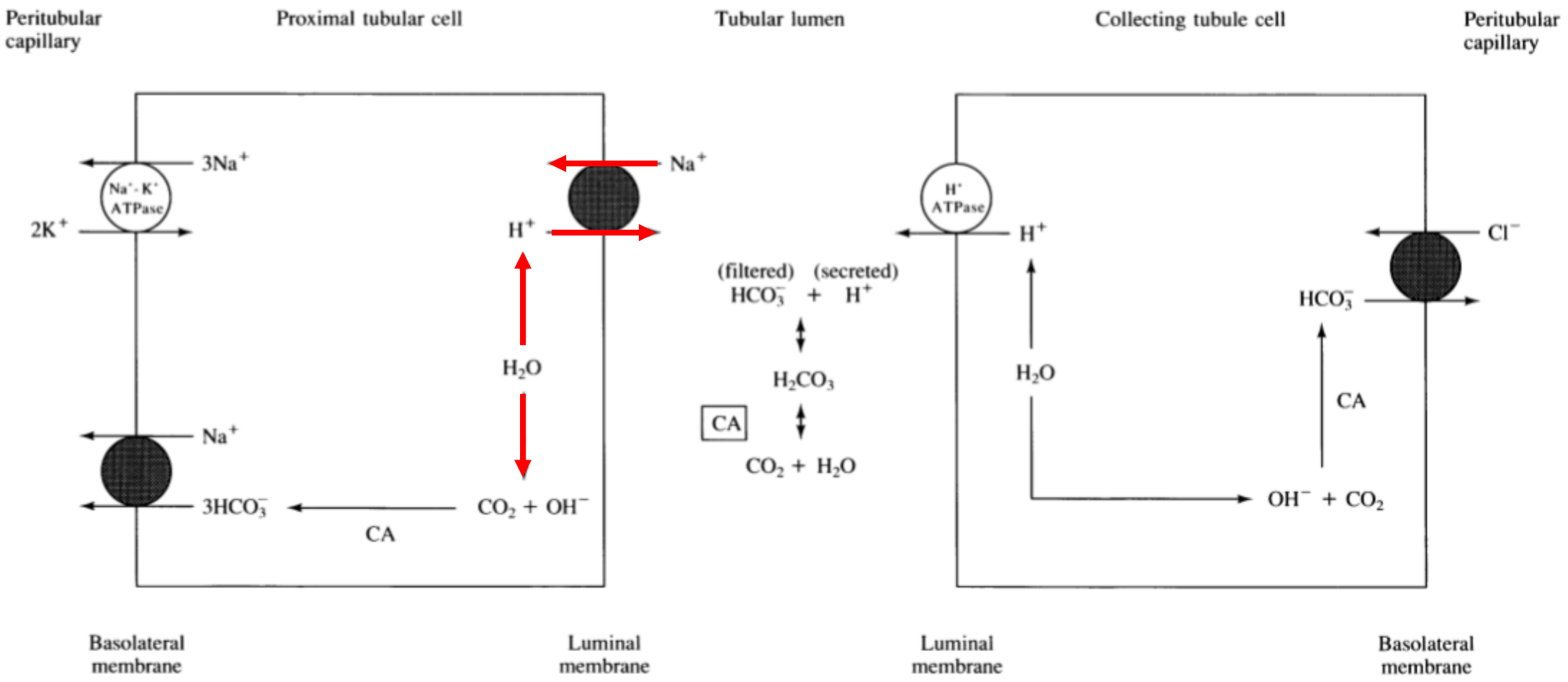

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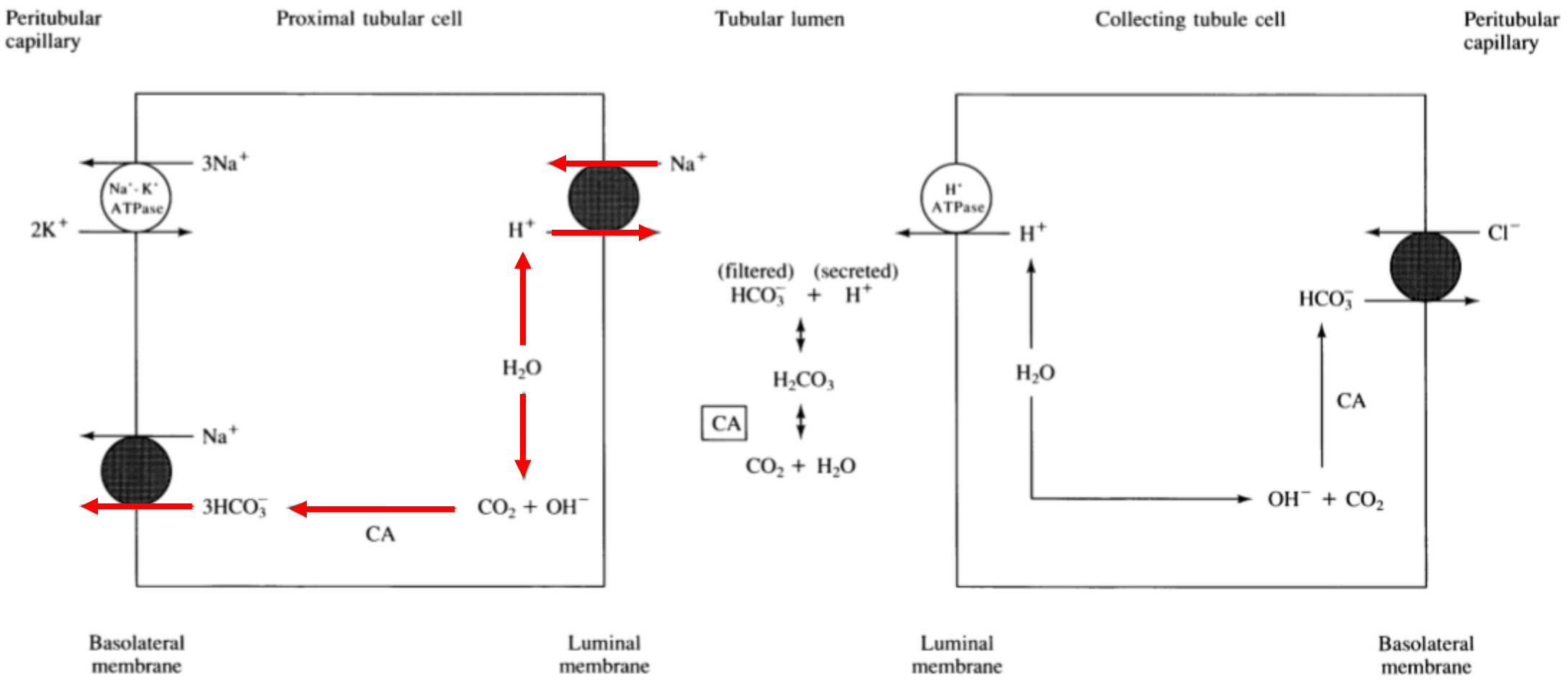

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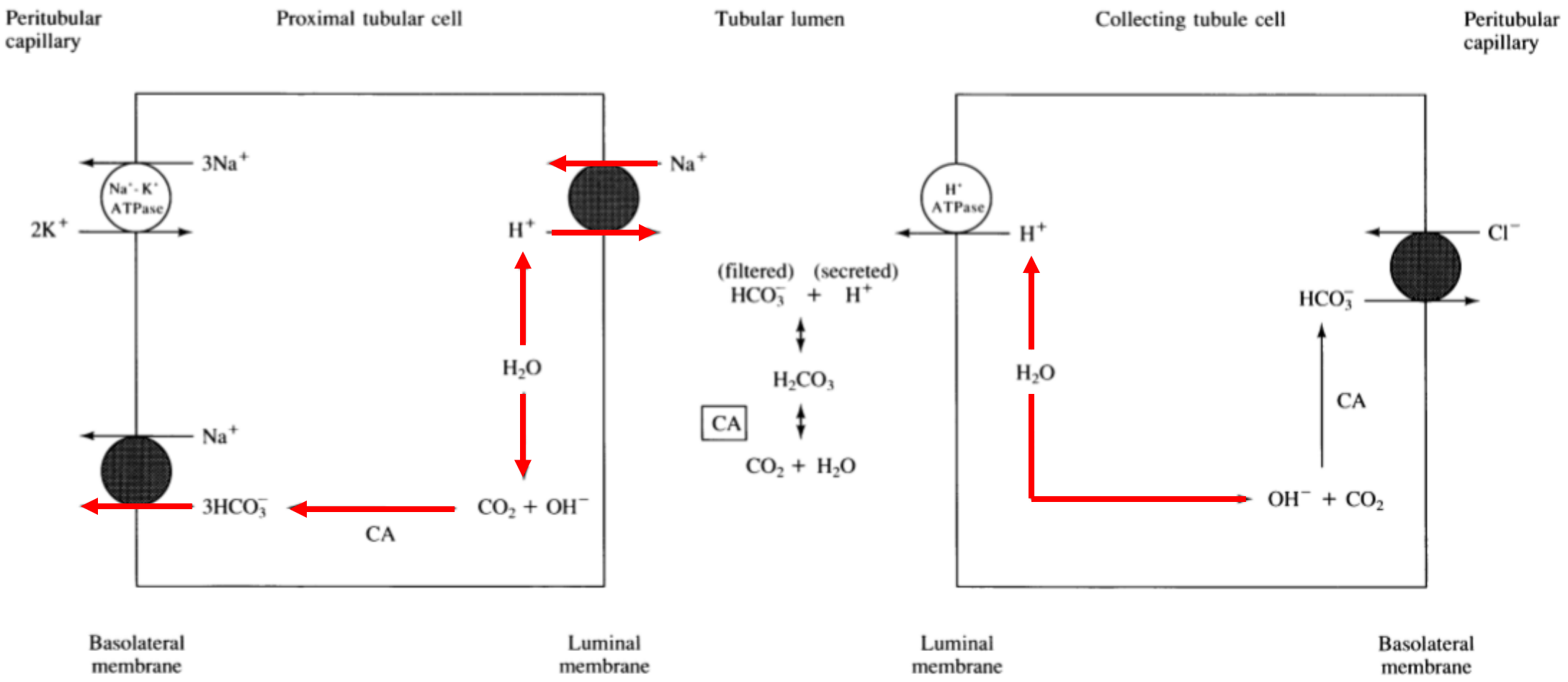

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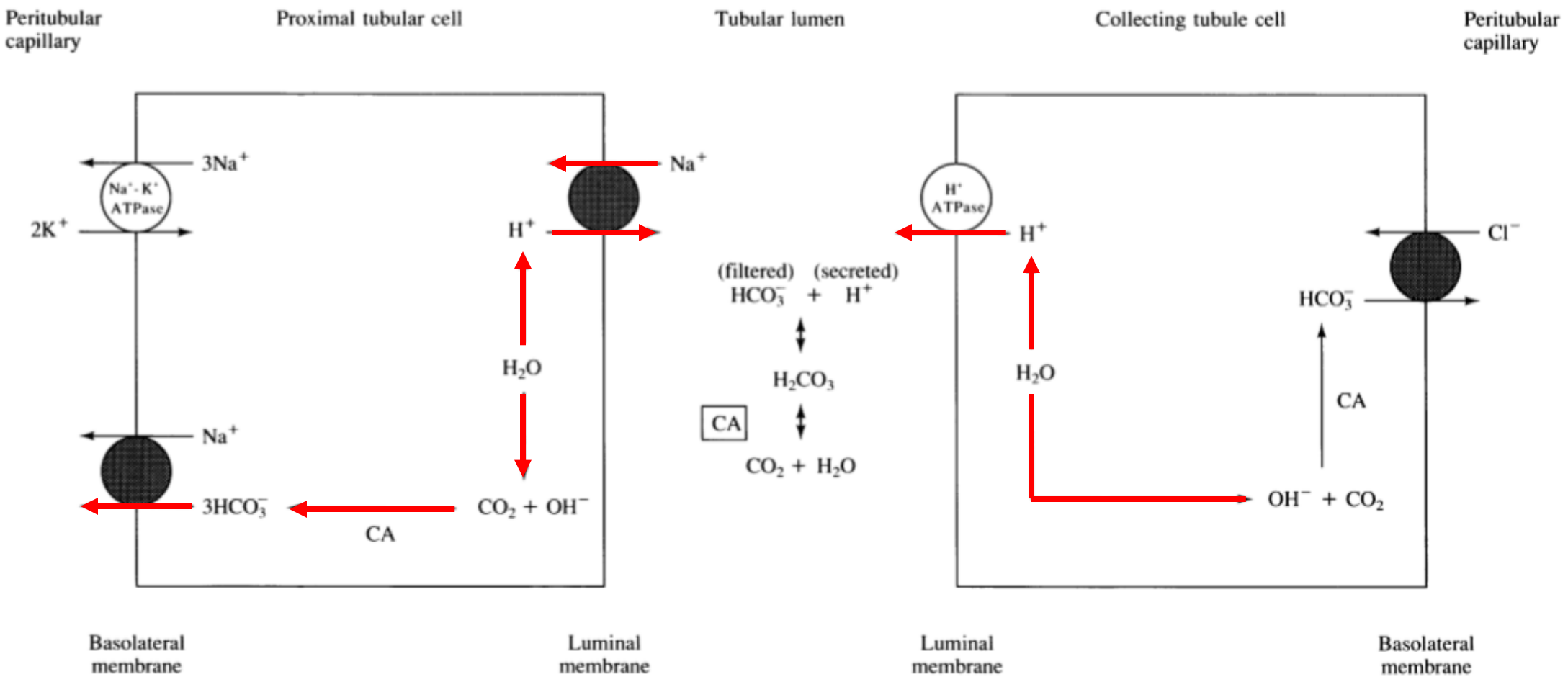

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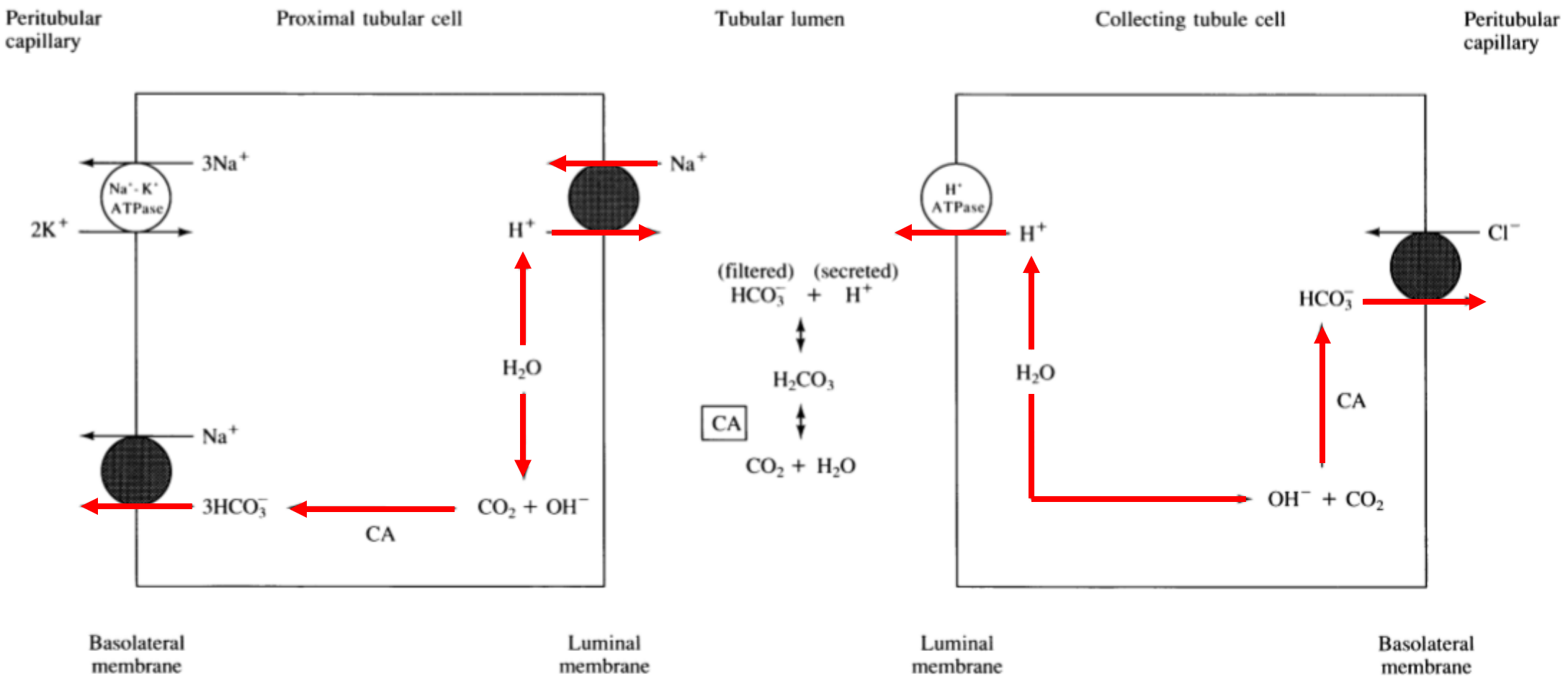

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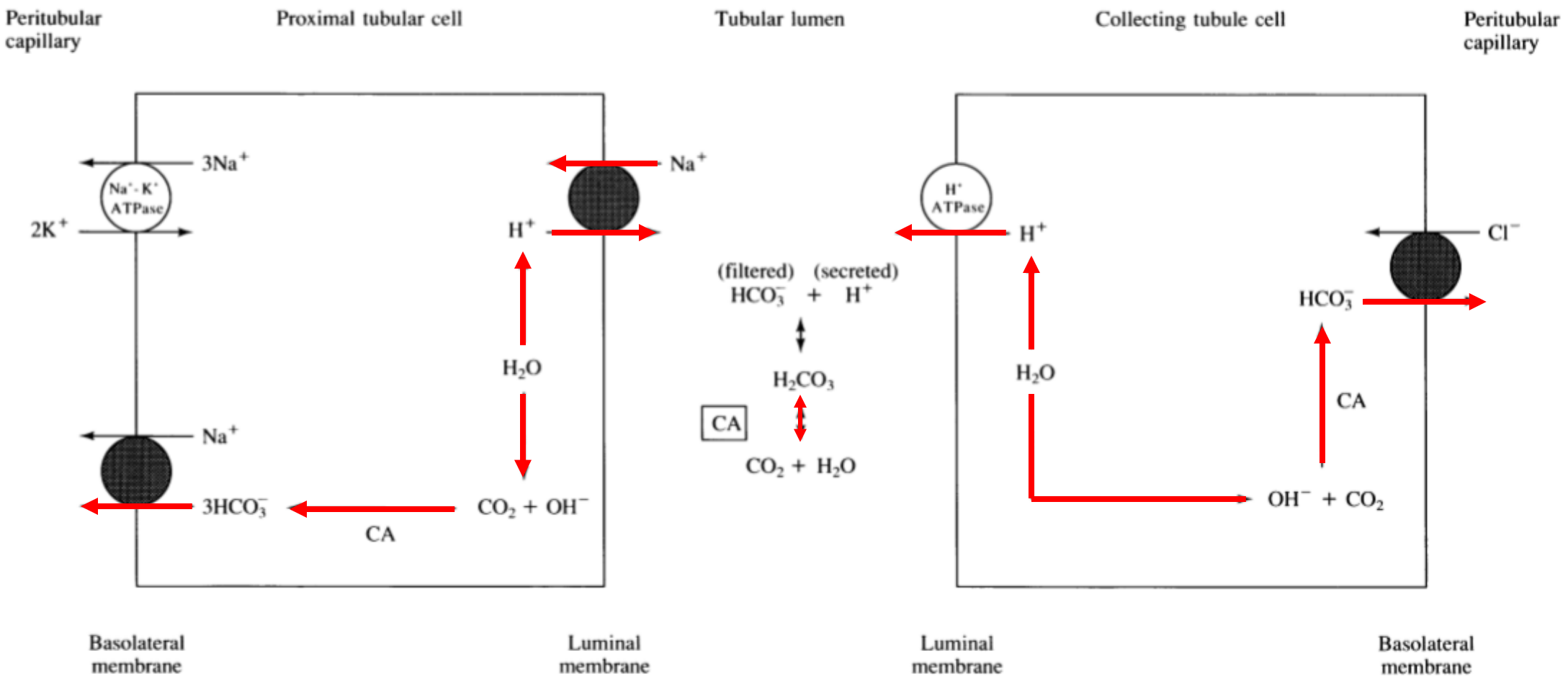
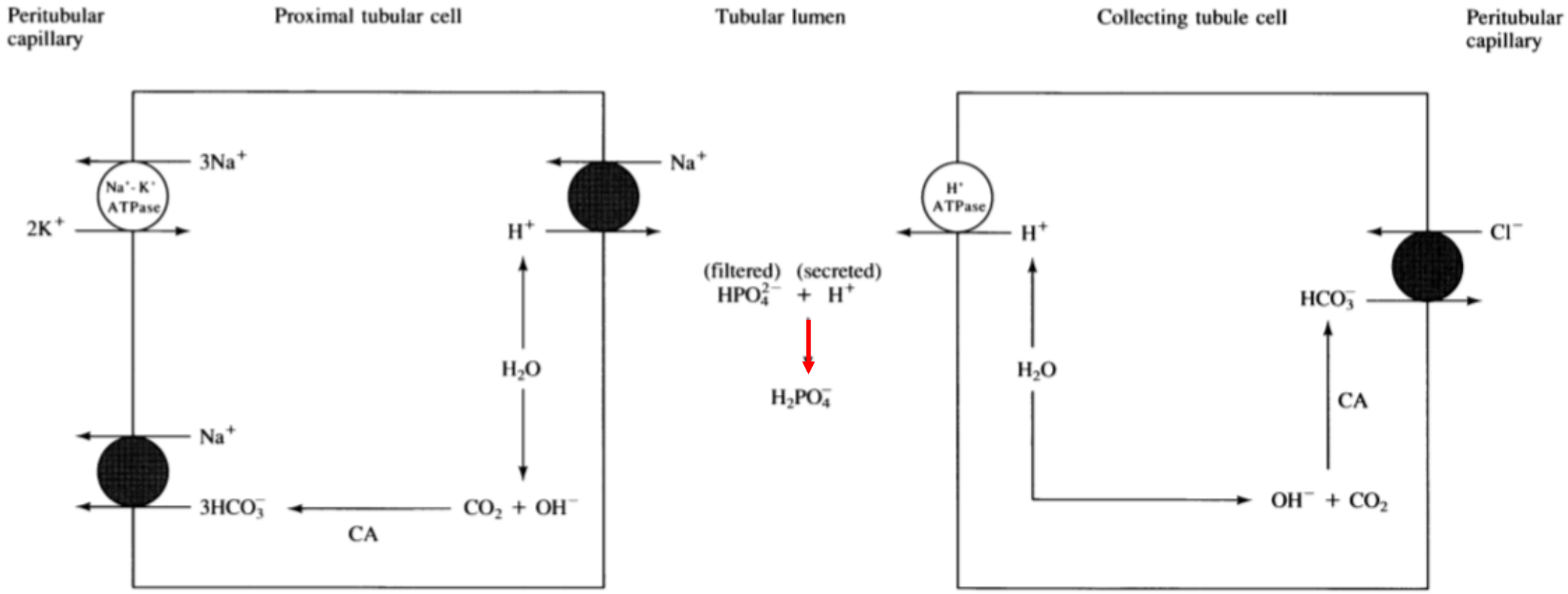


LEGEND FOR SLIDES ABOVE

Figure 11-2 Major cellular and luminal events in bicarbonate reabsorption in the proximal tubule and the collecting tubules. Intracellular H_2O breaks down into a H^+ ion and a OH^- ion. The latter combines with CO_2 to form HCO_3^-, via a reaction catalyzed by carbonic anhydrase (CA). In the proximal tubule, the H^+ is secreted into the lumen by the Na^+-H^+ exchanger, whereas the HCO_3^- is returned to the systemic circulation primarily by a Na^+-$3HCO_3^-$ cotransporter. These same processes occur in the collecting tubules, although they are respectively mediated by an active H^+-ATPase pump in the luminal membrane and a Cl^--HCO_3^- exchanger in the basolateral membrane. The secreted H^+ ions combine with filtered HCO_3^- to form carbonic acid (H_2CO_3) and then $CO_2 + H_2O$, which can be passively reabsorbed. This dissociation of carbonic acid is facilitated when luminal carbonic anhydrase (CA in box) is present, as occurs in the early proximal tubule (see text). The net effect is HCO_3^- reabsorption, even though the HCO_3^- ions returned to the systemic circulation are not the same as those that were filtered. Although not shown, the collecting tubule cells also have H^+-K^+-ATPase pumps in the luminal membrane that are primarily involved in K^+ reabsorption.

ACID-BASE BALANCE

3b. RENAL H^+ SECRETION

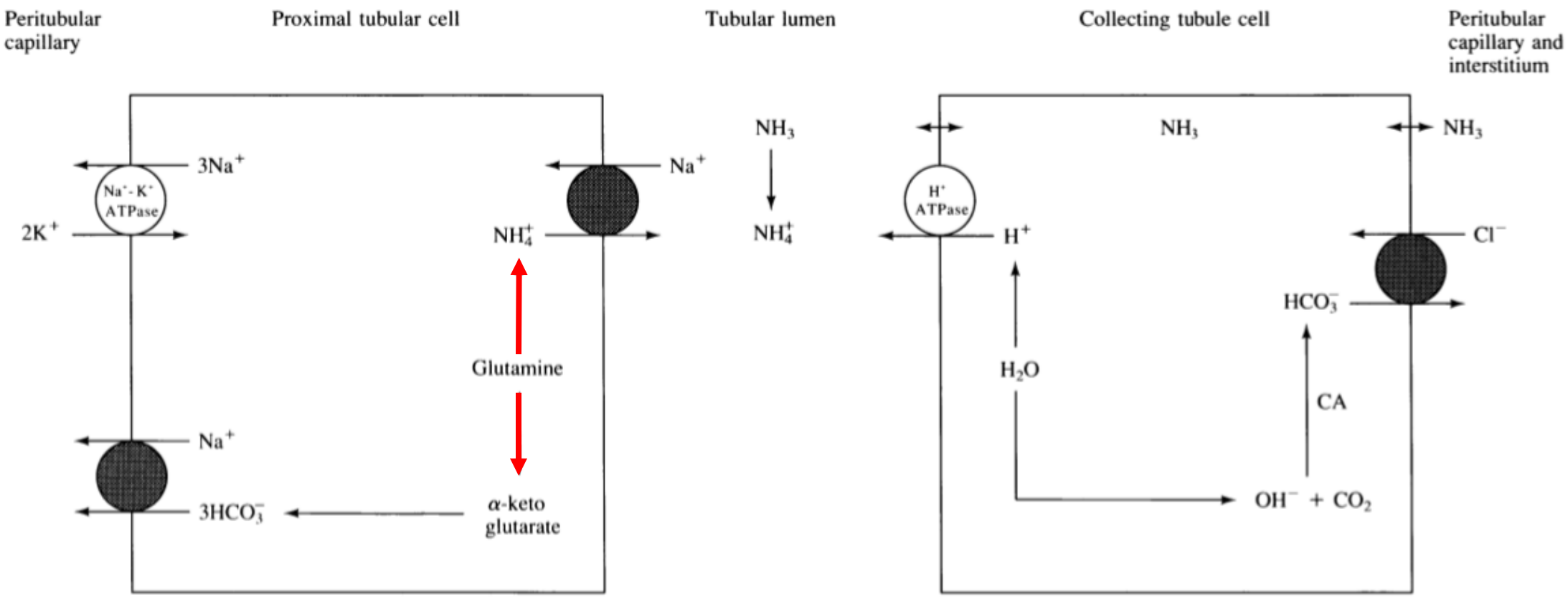


LEGEND FOR SLIDE ABOVE

Figure 11-3 Formation of titratable acidity, which is primarily due to buffering of secreted H^+ by filtered HPO_4^{2-} and, to a lesser degree, other buffers such as creatinine. Note that a new HCO_3^- ion is returned to the peritubular capillary for every H^+ ion that is secreted.

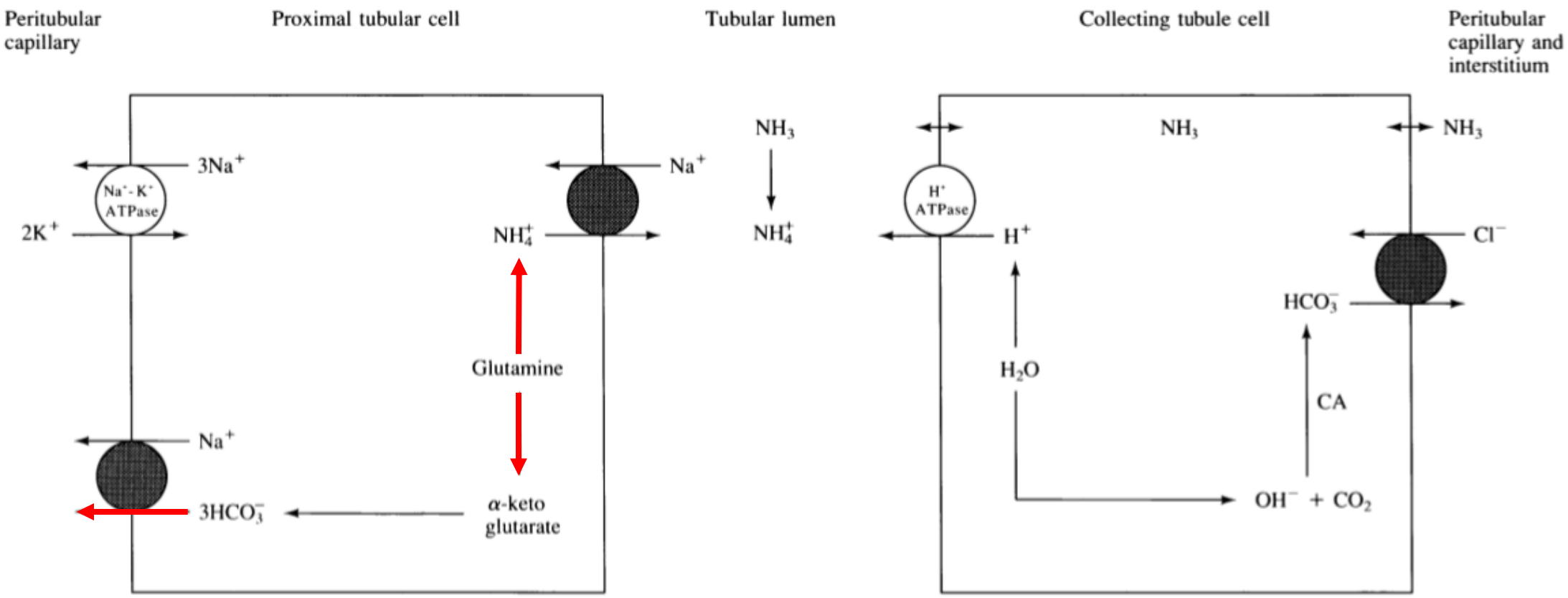
ACID-BASE BALANCE

3c. RENAL H^+ SECRETION



ACID-BASE BALANCE

3c. RENAL H^+ SECRETION



ACID-BASE BALANCE

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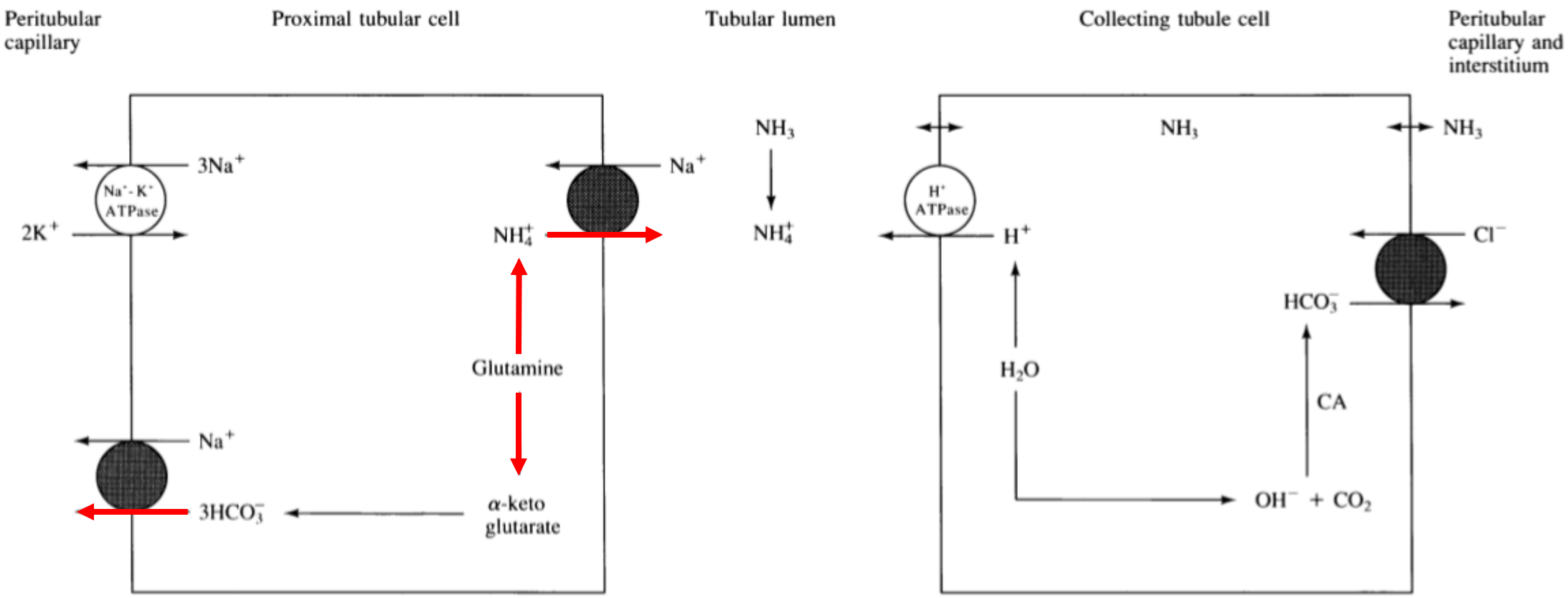
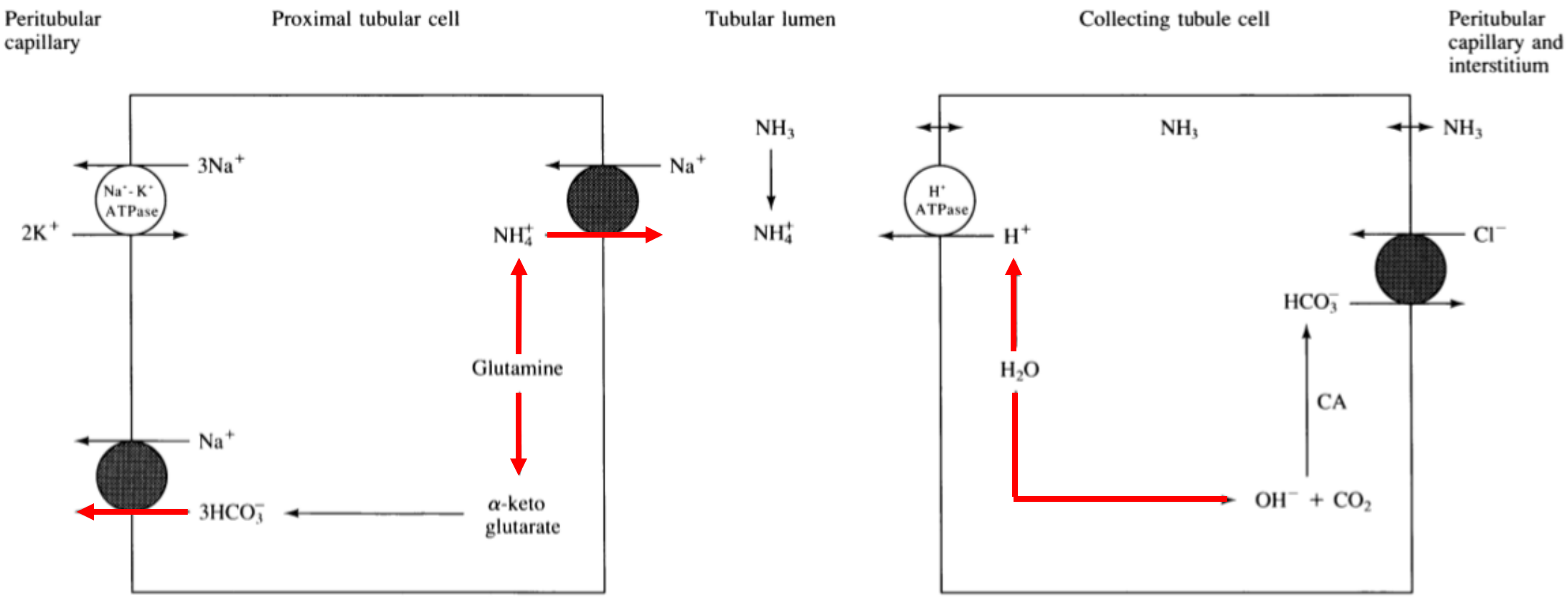


ACID-BASE BALANCE

3c. RENAL H^+ SECRETION



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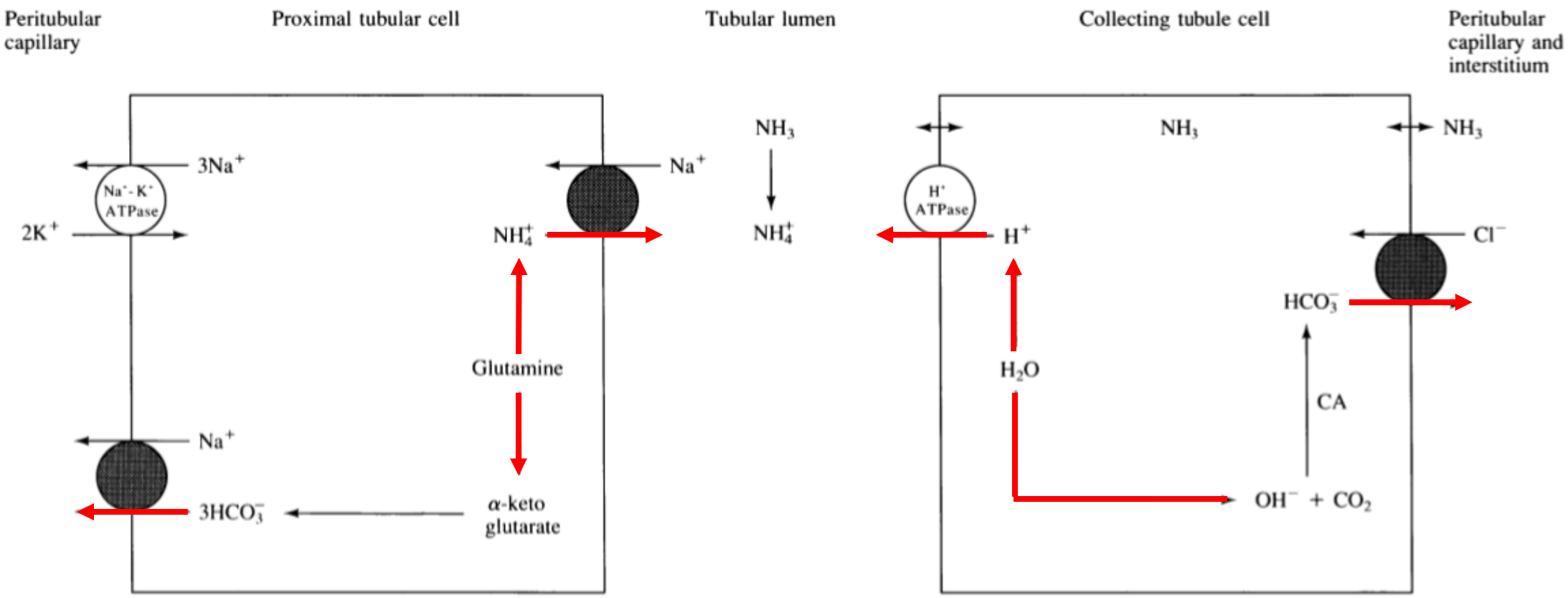

ACID-BASE BALANCE

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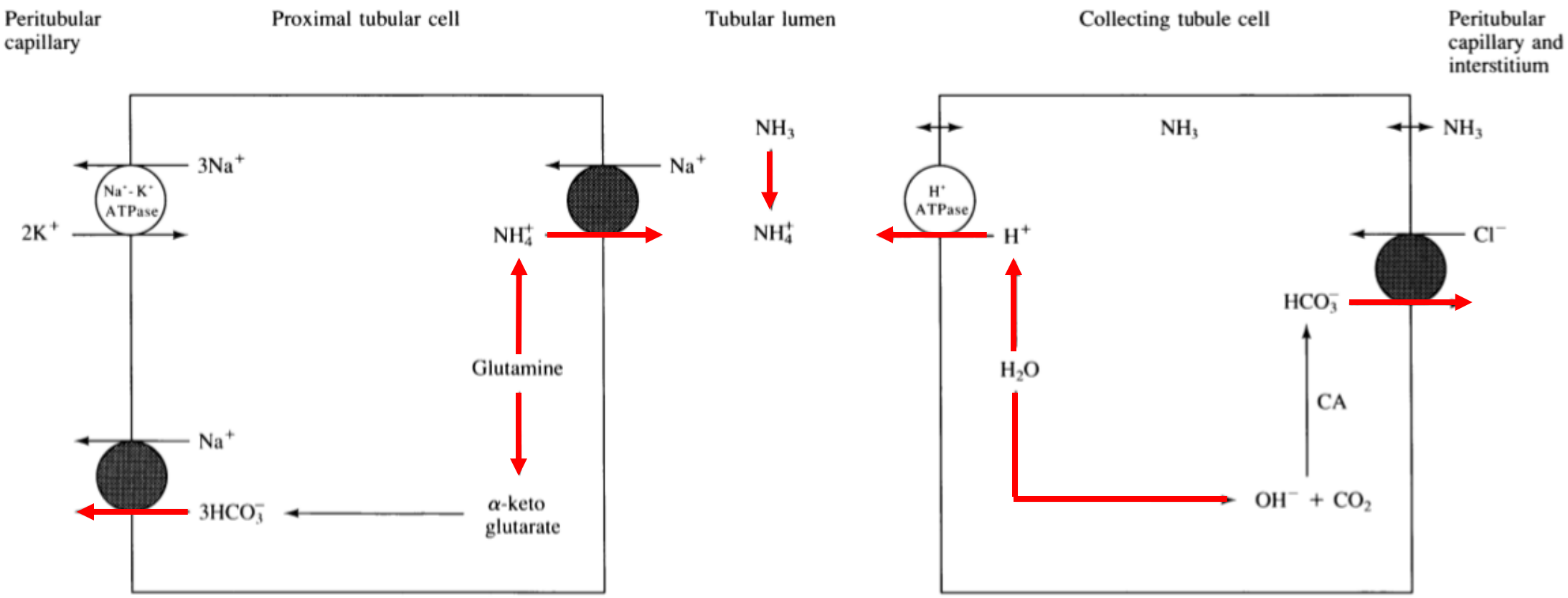


LEGEND FOR SLIDES ABOVE

Figure 11-4 Formation of urinary ammonium (NH_4^+). In the proximal tubule, glutamine is taken up by the cells and metabolized into NH_4^+ and α-ketoglutarate. Utilization of the latter results in the generation of HCO_3^-, whereas NH_4^+ substitutes for H^+ on the Na^+-H^+ exchanger and is then secreted directly into the lumen. The mechanism is different in the collecting tubules; nonpolar, lipid-soluble NH_3 diffused from the interstitial fluid into the lumen, where it combines with secreted H^+ to form NH_4^+. Ammonium is lipid-insoluble and is therefore unable to back-diffuse out of the lumen. Note that each NH_4^+ ion that is excreted is associated with the generation of a new HCO_3^- ion that is returned to the peritubular capillary.

ACID-BASE DISORDERS

1. Excessive acid or base addition into the organism
2. Disorder of **alveolar ventilation**
3. Disorder of **renal H+ excretion**

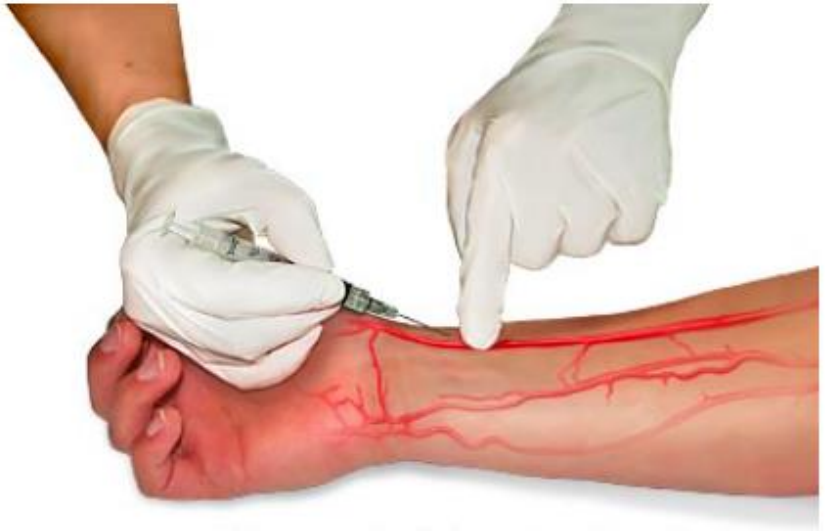
ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

Measurement of pH (arterial blood gases, ABGs):

- Blood drawn anaerobically in a heparinized syringe (to prevent loss of PCO2)
- Rapid measurement or cooling at 4°C (to prevent anaerobic glycolysis by RBCs and organic acid production by WBCs)
- Do not dilute blood specimen



After a pulse is found, a blood sample is taken from the artery

ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

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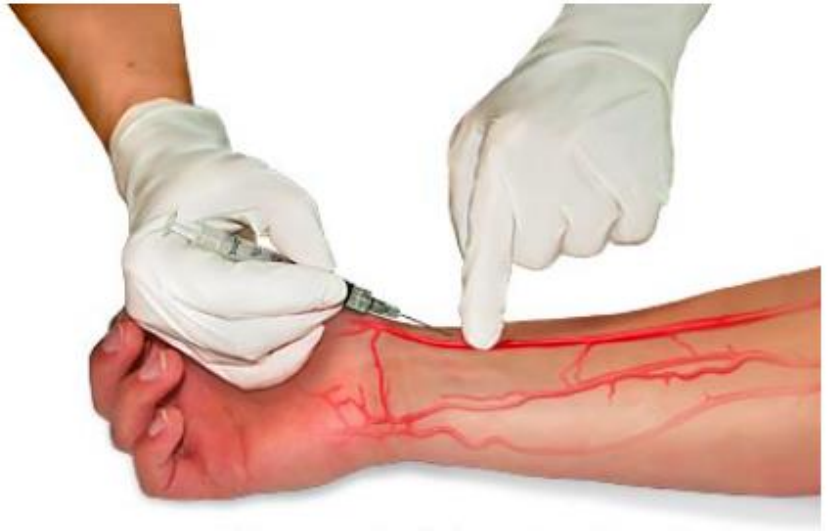
Normal values in ABGs:

	pH	HCO3 (mEq/L)	PCO2 (mmHg)
Arterial Blood	7.37-7.43	22-26	36-44
Venous Blood	7.32-7.38	23-27	42-50
	7.4	**24**	**40**



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ASSESSMENT OF ACID-BASE BALANCE

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	pH	Primary Disorder	Compensation
METABOLIC ACIDOSIS	↓	↓ [HCO3-]	↓ PCO2
METABOLIC ALKALOSIS	↑	↑ [HCO3-]	↑ PCO2
RESPIRATORY ACIDOSIS	↓	↑ PCO2	↑ [HCO3-]
RESPIRATORY ALKALOSIS	↑	↓ PCO2	↓ [HCO3-]

ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

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		pH	Primary disorder	Compensation
METABOLIC ACIDOSIS		↓	↓ [HCO3-] **1mEq/L**	↓ PCO2 **1.2 mmHg**
METABOLIC ALKALOSIS		↑	↑ [HCO3-] **1mEq/L**	↑ PCO2 **0.7 mmHg**
RESPIRATORY ACIDOSIS	ACUTE	↓	↑ PCO2 **10 mmHg**	↑ [HCO3-] **1 mEq/L**
	CHRONIC	↓	↑ PCO2 **10 mmHg**	↑ [HCO3-] **3.5 mEq/L**
RESPIRATORY ALKALOSIS	ACUTE	↑	↓ PCO2 **10 mmHg**	↓ [HCO3-] **2 mEq/L**
	CHRONIC	↑	↓ PCO2 **10 mmHg**	↓ [HCO3-] **4 mEq/L**

ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

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Self-assessment questions:

	pH	HCO3- (mEq/L)	PCO2 (mmHg)
Example 1	7.32	14	28

1. Is there an acid-base disorder?

ASSESSMENT OF ACID-BASE BALANCE

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Example 1	**7.32**	14	28

1. Is there an acid-base disorder?
2. Is the acid-base disorder an acidosis or an alkalosis?

ASSESSMENT OF ACID-BASE BALANCE

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ASSESSMENT OF ACID-BASE BALANCE

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1. Is there an acid-base disorder?
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3. Is the acid-base disorder metabolic or respiratory? **METABOLIC**
4. Which is the compensation of the organism?

ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

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1. Is there an acid-base disorder?
2. Is the acid-base disorder an acidosis or an alkalosis? **ACIDOSIS**
3. Is the acid-base disorder metabolic or respiratory? **METABOLIC**
4. Which is the compensation of the organism? **Reduction in PCO2**

ASSESSMENT OF ACID-BASE BALANCE

Henderson-Hasselbach equation:

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

Self-assessment questions:

	pH	HCO3- (mEq/L)	PCO2 (mmHg)
Example 1	7.32	14	28
Example 2	7.47	20	14
Example 3	7.08	14	49
Example 4	7.51	38	49

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Berne and Levy Physiology, ELSEVIER 2018

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CLINICAL CASE 1

A 38-year-old man presented to an emergency department with progressive weakness and decreased urine output after having vomited up to 20 times per day over a period of 7 days. The patient was referred to our intensive care unit. Before medical consultation, he was healthy, and no other symptoms were reported. Diarrhea, fever, chills, or abdominal pain was absent.

Heymer J et al. Ind J Crit Care Med 2018; 22:883

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Clinical examination revealed a patient of normal weight (height: 180 cm, weight: 70 kg). Blood pressure and heart rate were elevated (150/80 mmHg, 105/min); the respiratory rate was normal (13/min), but oxygen saturation was low (89%). During blood pressure measurement, a positive Trousseau sign was noted. The mucous membranes were dry, and the physical examination was otherwise unremarkable.

Heymer J et al. Ind J Crit Care Med 2018; 22:883

CLINICAL CASE 1

BIOCHEMISTRY (BLOOD)		ABGs		BIOCHEMISTRY (URINE)	
Ure (mg/dl)	176	pH	7.71	Cl (mEq/L)	?
Cre (mg/dl)	5.2	HCO3- (mEq/L)	72	Na (mEq/L)	?
Na (mEq/L)	130	PCO2 (mmHg)	56.1		
K (mEq/L)	2.4				
Cl (mEq/L)	52				
Ca++ (mmol/L)	0.7				

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CLINICAL CASE 1

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

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CLINICAL CASE 1

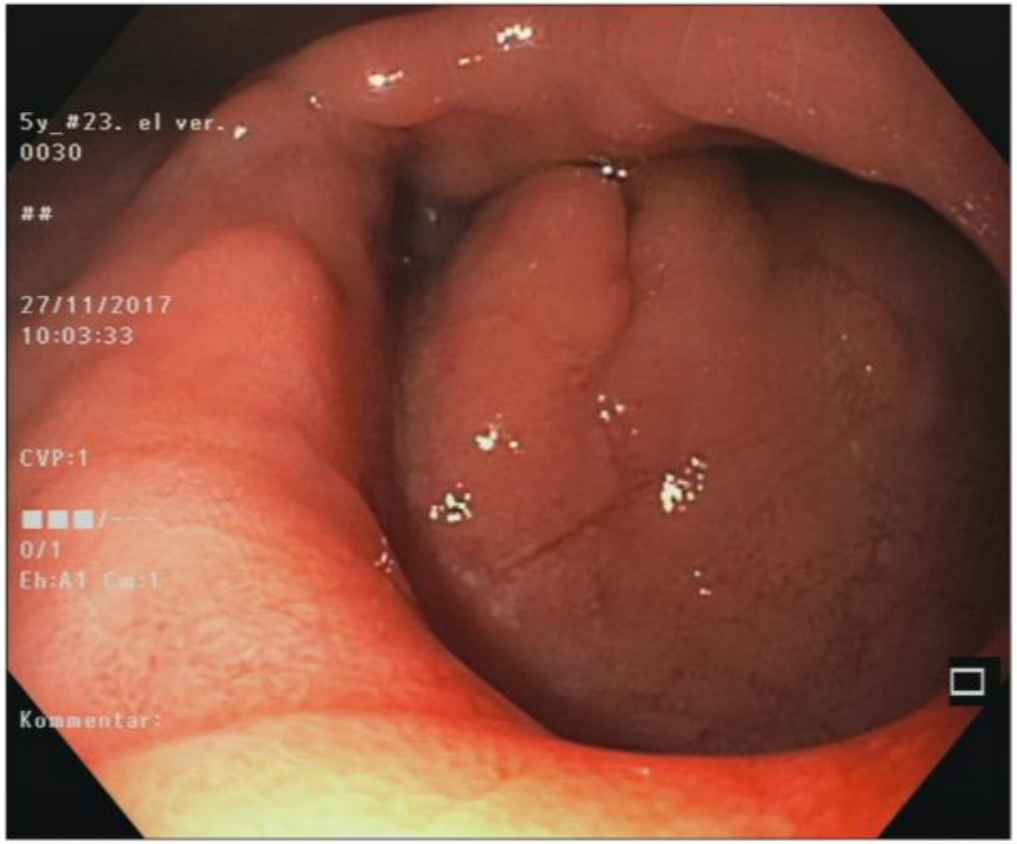

Figure 2: Gastrointestinal endoscopy. Endoscopy revealing an obstruction of the duodenum. Further, imaging with magnetic resonance imaging and endosonography excluded a compression by a neoplastic process

Heymer J et al. Ind J Crit Care Med 2018; 22:883

CLINICAL CASE 1 - DISCUSSION

METABOLIC ALKALOSIS

PATHOGENESIS

GENERATION PHASE : Gastrointestinal H+ loss

MAINTENANCE PHASE: Hypochloremia

Hypokalemia

Hypovolemia (pre-renal acute kidney injury)

SIGNS AND SYMPTOMS

UNDERLYING DISEASE (obstruction of the duodenum): vomiting

CURRENT DISEASE (hypovolemia): hypotension, increased HR, dry mucous membranes

(hypocalcemia): tetany, Trousseau's sign

Case Rep Gastroenter 2012

CLINICAL CASE 1 - DISCUSSION

The Trousseau sign of latent tetany is a way to determine if an individual may have hypocalcemia. Trousseau's sign is considered positive when **a carpopedal spasm of the hand and wrist occurs after an individual wears a blood pressure cuff inflated over their systolic blood pressure for 2 to 3 minutes**.

Case Rep Gastroenter 2012

CLINICAL CASE 2

A 60-year-old male patient was admitted to our hospital with epileptic seizures and dehydration. Clinical examination revealed a delirious patient with skin and mucosal dryness. Family members reported on recurrent vomiting. There was no regular medication taken by the patient. Magnetic resonance imaging excluded cerebral bleeding and ischemia.

Case Rep Gastroenter 2012

CLINICAL CASE 2

BIOCHEMISTRY (BLOOD)		ABGs		BIOCHEMISTRY (URINE)	
Ht (%)	54	pH	7.56	Cl (mEq/L)	5
Ure (mg/dl)	80	HCO3- (mEq/L)	42	Na (mEq/L)	44
Cre (mg/dl)	1.8	PCO2 (mmHg)	53		
Na (mEq/L)	145				
K (mEq/L)	2.7				
Cl (mEq/L)	<60				

Case Rep Gastroenter 2012

CLINICAL CASE 2

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

BIOCHEMISTRY (BLOOD)		ABGs		BIOCHEMISTRY (URINE)	
Ht (%)	54	pH	7.56	Cl (mEq/L)	5
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Case Rep Gastroenter 2012

CLINICAL CASE 2

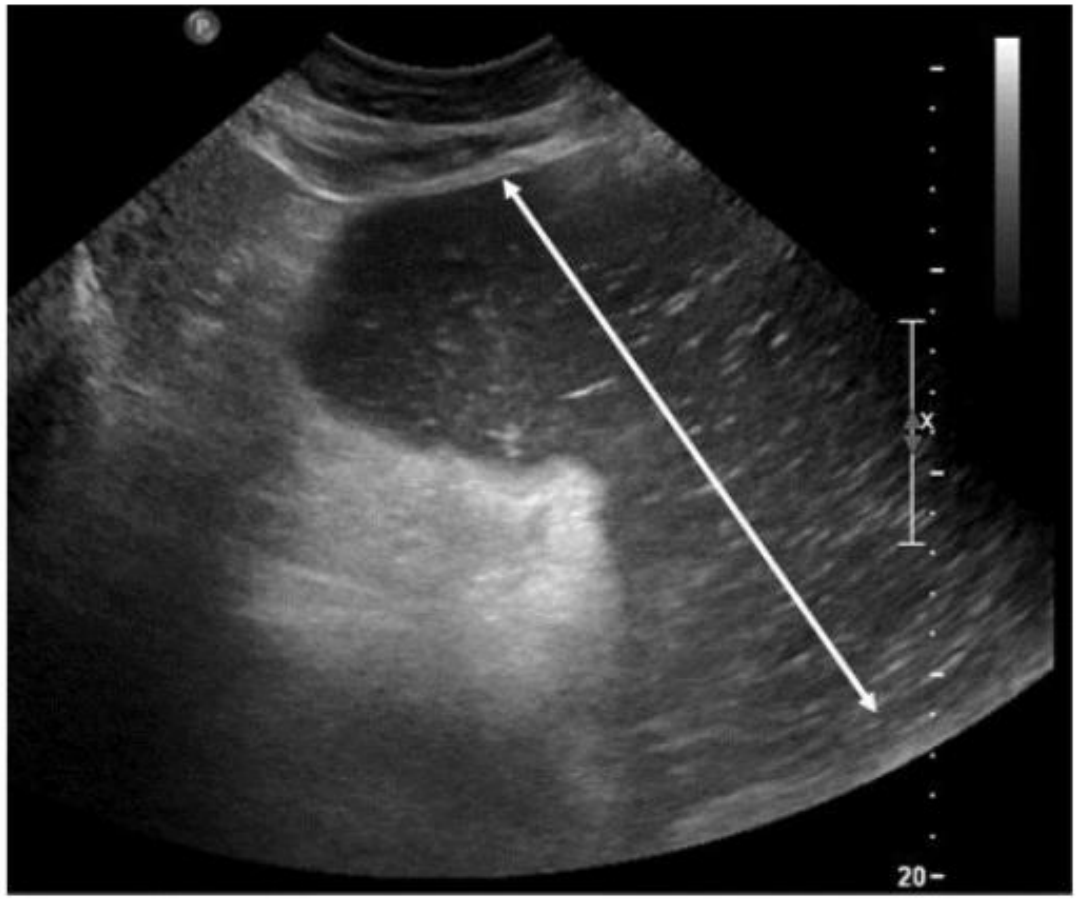

Fig. 1. Abdominal ultrasound showed an enlarged stomach

Case Rep Gastroenter 2012

CLINICAL CASE 2

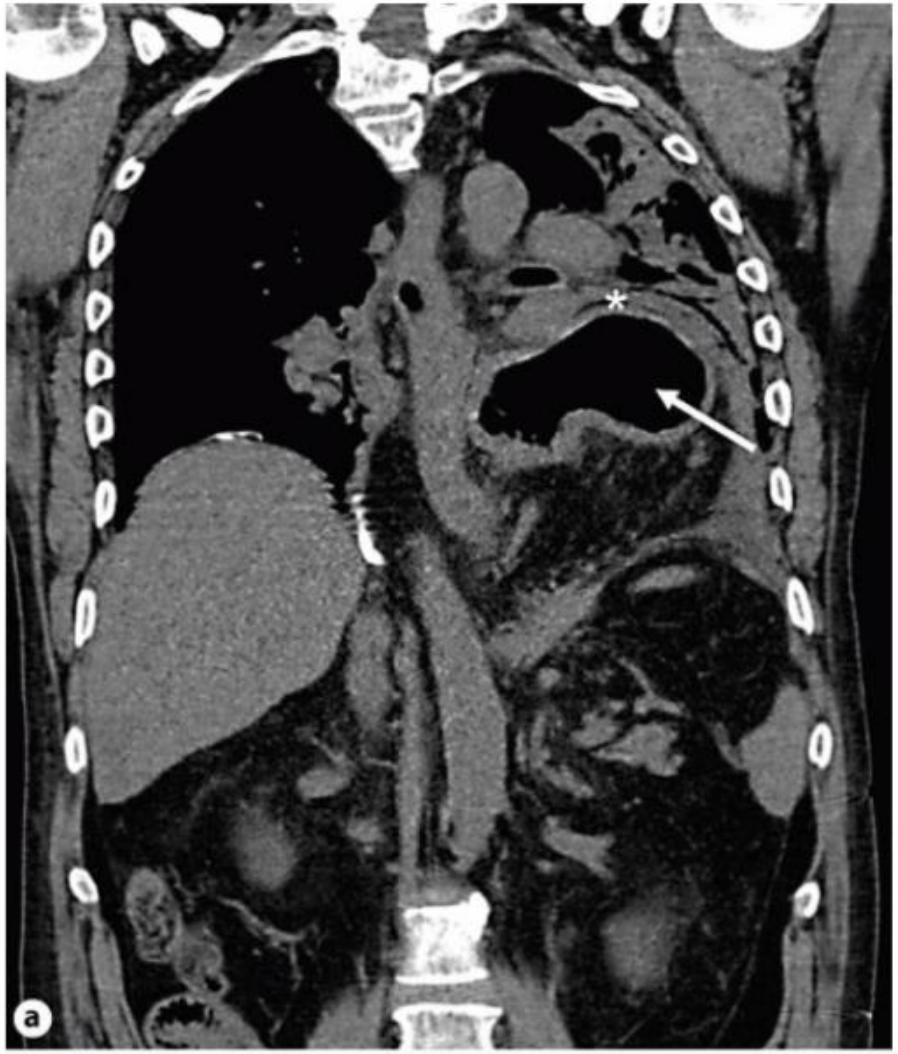

Fig. 3. **a** Thoracoabdominal computed tomography showed a hiatal hernia 3.5 cm in diameter and an intrathoracic upside-down stomach (white arrow) surrounded by a fluid fringe (asterisk) as a sign of

Case Rep Gastroenter 2012

CLINICAL CASE 2

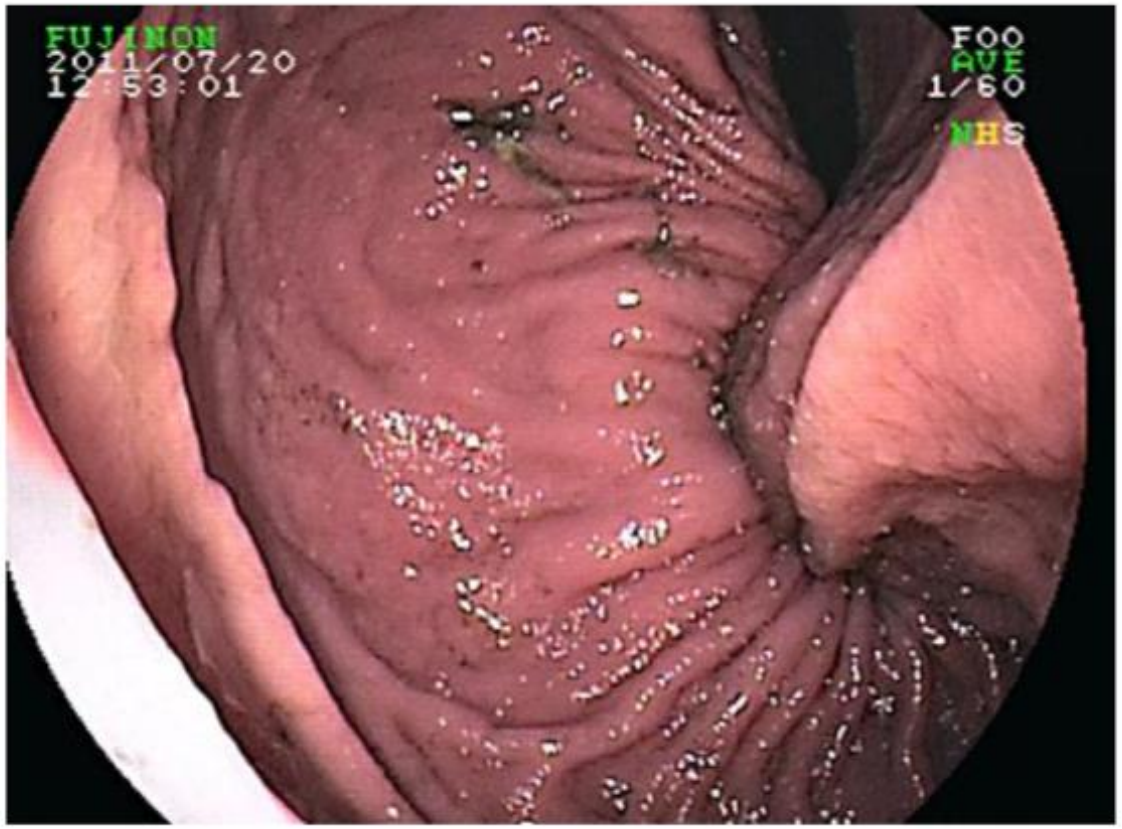

Fig. 2. By esophagogastroduodenoscopy we diagnosed a large hiatal hernia with an intrathoracic pylorus and multiple mucosal hemorrhages as signs of incipient incarceration. The fact that 3 l of fluid were initially removed from the esophagus and stomach confirmed gastric outlet obstruction.

Case Rep Gastroenter 2012

THEREFORE …

METABOLIC ALKALOSIS

PATHOGENESIS

GENERATION PHASE

1. H+ LOSS

A. GASTROINTESTINAL LOSS

(a) Vomiting, nasogastric tube

(b) Congenital chloridorrhea

Villous adenoma

Laxatives

B. KIDNEY LOSS

(a) Diuretics

(b) Hyperaldosteronism

(c) Hypocalcemia

Γ. TRANSLOCATION INTO THE CELLS

(a) Hypokalemia

2. HCO3- ADDITION

A. MASSIVE TRANSFUSIONS

B. NaHCO3 ADMINISTRATION

MAINTENANCE PHASE

1. **HYPOVOLEMIA**
2. **HYPOCHLOREMIA**
3. **HYPOKALEMIA**

METABOLIC ALKALOSIS

SIGNS AND SYMPTOMS

ASYMPTOMATIC

UNDERLYING DISEASE

History: vomiting, diarrhea, laxatives

Clinical examination: nasogastric tube

VOLUME AND ELECTROLYTE DISORDERS

Hypovolemia

Weakness, dry mucous membranes and skin, hypotension, thirst, muscle cramps

Hypokalemia

Polyuria, thirst, muscle weakness, arrythmia

Hypocalcemia

Muscle spasm, tetany, paresthesia, seizures, coma

METABOLIC ALKALOSIS

DIAGNOSIS

ABGs

↑ pH

[HCO3-] ↑ 1 mEq/L

PCO2 ↑ 0.7 mmHg

BLOOD BIOCHEMISTRY

Hypokalemia

Hypochloremia

URINE BIOCHEMISTRY

Na >10 mmol/L

Cl <10-20 mmol/L

OUTLINE

INTRODUCTION

Acid-base balance, arterial blood gases (ABGs), introduction to acid-base disorders

METABOLIC ALKALOSIS

Clinical case

Pathogenesis - Signs and symptoms - Diagnosis

METABOLIC ACIDOSIS

Clinical case

Pathogenesis - Signs and symptoms - Diagnosis

RESPIRATORY ALKALOSIS AND ACIDOSIS

Clinical cases

Pathogenesis - Signs and symptoms - Diagnosis

Berne and Levy Physiology, ELSEVIER 2018

BD Rose and T Post. Clinical Physiology of Acid-Base and Electrolyte Disorders. McGraw Hill 2000

CLINICAL CASE 3

Patient: Mr. Johnson, a 45-year-old male

Chief Complaint: Shortness of breath and chest pain

History of Present Illness: Mr. Johnson was admitted to the hospital with a three-day history of shortness of breath and chest pain. He also reported a fever, cough with yellow-green sputum, and fatigue. He has a history of smoking and a history of alcohol abuse.

Past Medical History: Mr. Johnson has a history of hypertension, which is well-controlled with medication. He also has a history of obstructive sleep apnea, for which he uses a continuous positive airway pressure (CPAP) machine.

Medications: Lisinopril 20 mg once daily, metoprolol 25 mg once daily

Physical Examination: Mr. Johnson appeared uncomfortable and was using accessory muscles to breathe. His blood pressure was 120/80 mmHg, heart rate was 110 beats per minute, and respiratory rate was 28 breaths per minute. Lung examination revealed crackles in both lung fields, and his oxygen saturation was 88% on room air.

elevated to 16,000/mm3, and his chest X-ray showed an infiltrate in the right lower lobe.

ChatGPT

CLINICAL CASE 3

BIOCHEMISTRY (BLOOD)		ABGs	
Ht (%)	40	pH	7.21
Ure (mg/dl)	80	HCO3- (mEq/L)	6
Cre (mg/dl)	2	PCO2 (mmHg)	18.4
Na (mEq/L)	140	Lactic acid (mmol/L)	5.23
K (mEq/L)	4.9		
Cl (mEq/L)	110		

CLINICAL CASE 3

$$pH = 6.10 + \log \frac{[HCO3-]}{0.03 \times PCO2}$$

BIOCHEMISTRY (BLOOD)		ABGs	
Ht (%)	40	pH	7.21
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Cl (mEq/L)	110		

CLINICAL CASE 3

CATIONS = ANIONS

PLASMA

$Na^+ + NMC = \mathbf{HCO_3^-} + Cl^- + \mathbf{NMA}$

140 6 110

Anion Gap = **NMA**-NMC = $Na^+ - (\mathbf{HCO_3^-} + Cl^-)$ **= 24**

Normal value = 10 +/- 2 mmol/L

NORMOCHLOREMIC

METABOLIC ACIDOSIS

WITH INCREASED ANION GAP

CLINICAL CASE 4

A 59-year-old woman came to Fujita Health University Hospital with complaints of general weakness and numbness of the fingers and was admitted for treatment. At the age of 29 years, she had undergone total hysterectomy due to uterine cancer, followed by radiotherapy. After the procedure, she experienced lack of uresiesthesia and an inability to completely empty her bladder, necessitating clean intermittent self-catheterization. From 2 years prior to admission, she had begun to experience occasional watery diarrhea. Four months before admission, she suffered from acute pyelonephritis and was treated with antibiotics. However, no urological examinations were conducted to clarify the cause of the pyelonephritis. Five days before admission, after she had eaten raw oysters, watery diarrhea had developed, with fever and vomiting. Because she experienced general weakness and numbness of the fingers, she was transferred to our hospital. She was lethargic but conscious and alert. Her weight was 37.4 kg (5 kg below usual weight); body temperature was 36.2°C, blood pressure was 116/72 mm Hg, pulse was 72 beats/min with regular sinus rhythm, and respiration rate was 16/min.

Physical examination was unremarkable except for muscle weakness of 4/5 in both upper and lower extremities.

Clin Exper Nephrol 2007

CLINICAL CASE 4

BIOCHEMISTRY (BLOOD)		ABGs		BIOCHEMISTRY (URINE)	
Ht (%)	28.3	pH	7.14	Cl (mEq/L)	132
Ure (mg/dl)	42	HCO3- (mEq/L)	3	Na (mEq/L)	70
Cre (mg/dl)	1	PCO2 (mmHg)	14	K (mEq/L)	9
Na (mEq/L)	140				
K (mEq/L)	3				
Cl (mEq/L)	130				

Clin Exper Nephrol 2007

CLINICAL CASE 4

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

BIOCHEMISTRY (BLOOD)		ABGs		BIOCHEMISTRY (URINE)	
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Na (mEq/L)	140				
K (mEq/L)	3				
Cl (mEq/L)	130				

Clin Exper Nephrol 2007

CLINICAL CASE 4

CATIONS = ANIONS

PLASMA

$Na^+ + NMC = HCO_3^- + Cl^- + NMA$

Anion Gap = NMA-NMC = $Na^+ - (HCO_3^- + Cl^-)$

Normal value = 10 +/- 2 mmol/L

URINE

$Na^+ + K^+ + NMC = Cl^- + NMA$

Anion Gap = NMA-NMC = $Na^+ + K^+ - Cl^-$

CLINICAL CASE 4

CATIONS = ANIONS

PLASMA

$Na^+ + NMC = \mathbf{HCO_3^- + Cl^-} + NMA$

140 **3** **130**

Anion Gap = NMA-NMC = $Na^+ - (\mathbf{HCO_3^- + Cl^-})$ **= 11**

Normal value = 10 +/- 2 mmol/L

HYPERCHLOREMIC

METABOLIC ACIDOSIS

WITH NORMAL ANION GAP

URINE

$Na^+ + K^+ + NMC = Cl^- + NMA$

70 **9** **132**

Anion Gap = NMA-**NMC** = $Na^+ + K^+ - Cl^-$ **= NEGATIVE**

EXTRARENAL CAUSE

CLINICAL CASE 4

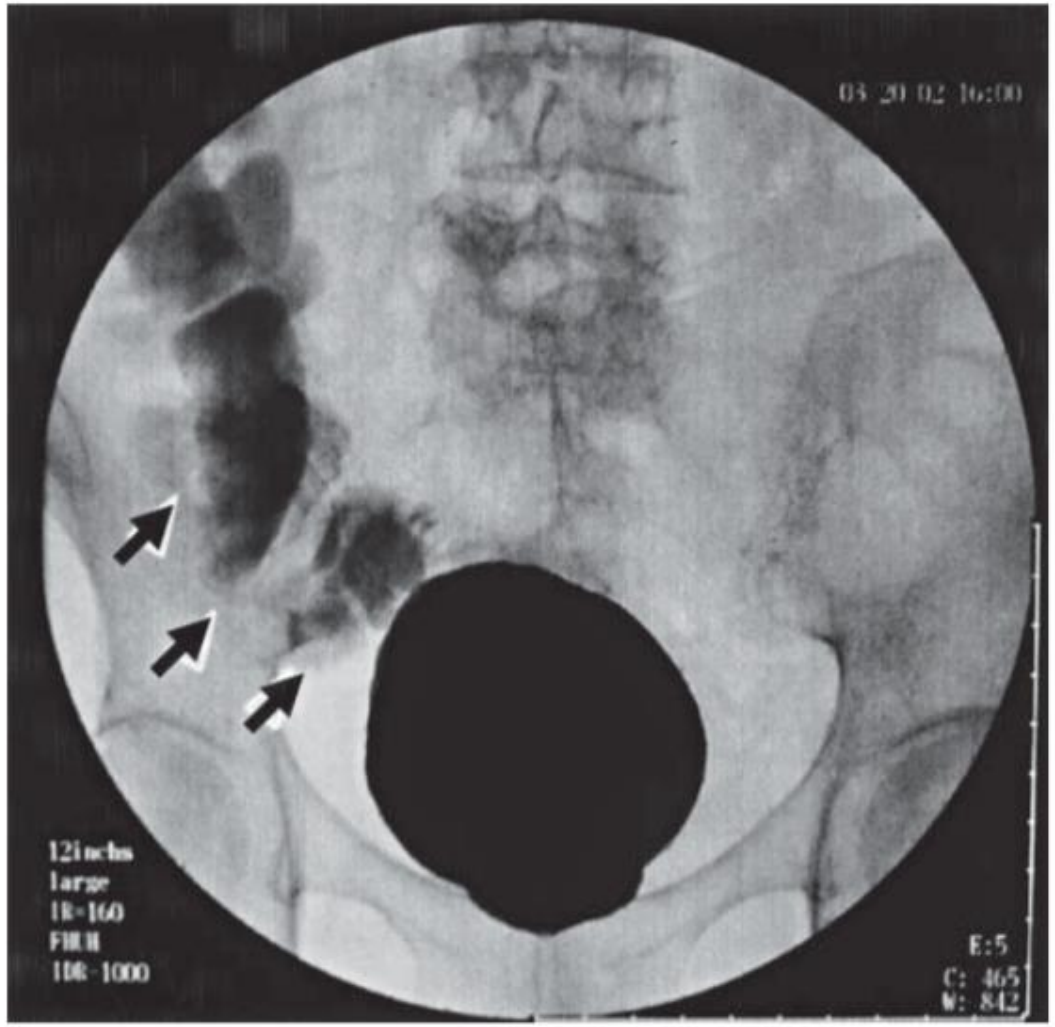
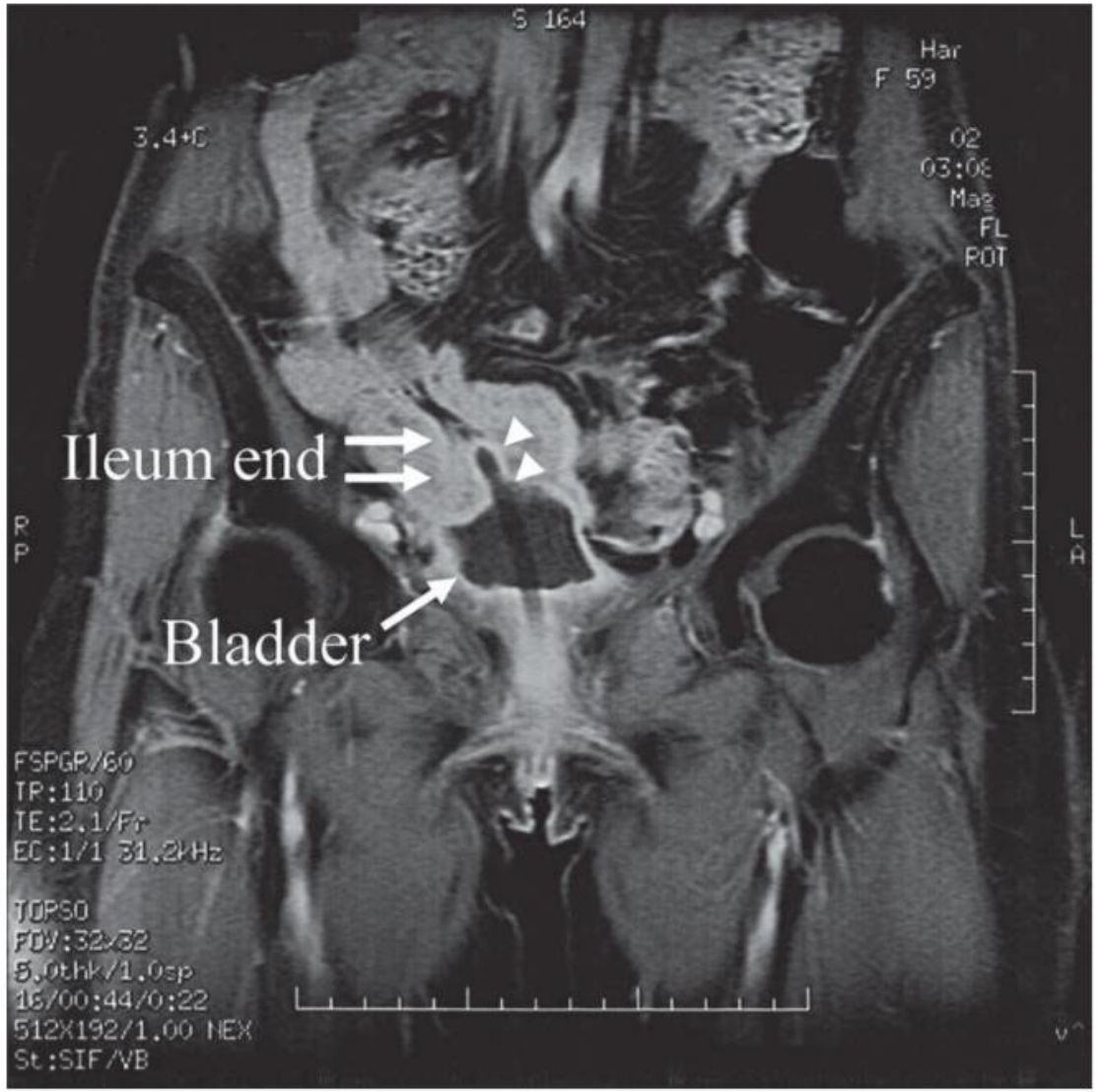


Fig. 2. Voiding cystourethrogram showed preferential drainage of contrast medium in the bladder into the ascending colon (*arrows*)

Clin Exper Nephrol 2007

CLINICAL CASE 4

Fig. 3. Pelvic portion magnetic resonance imaging showed that the catheter tip installed in the bladder was located in the end of the ileum (*arrow heads*)



Clin Exper Nephrol 2007

THEREFORE …

METABOLIC ACIDOSIS

PATHOGENESIS AND CLASSIFICATION

HYPERCHLOREMIC WITH NORMAL ANION GAP

1. EXTRARENAL CAUSES

   (Increased renal H+ excretion, negative UAG)

   (a) Diarrhea

   (b) Ureterosigmoidostomy

   (c) Pancreatic, biliary or intestinal fistula

2. RENAL CAUSES

   (Reduced renal H+ secretion, positive UAG)

   (a) Type I RTA (distal tubule, impaired H+ secretion)

   (b) Type II RTA (proximal tubule, impaired HCO3- reabsorption)

   (c) Type IV RTA

   (d) Renal failure (GFR>15-20 ml/min)

NORMOCHLOREMIC WITH INCREASED ANION GAP

1. EXTRARENAL CAUSES

(a) Lactic acidosis

(b) Diabetic acidosis

(c) Fasting

(d) Ethanol, methanol, salicylate intoxication

2. RENAL CAUSES

(a) Uremic acidosis (GFR< 10 ml/min)

METABOLIC ACIDOSIS

PATHOGENESIS AND CLASSIFICATION

TYPE IV RENAL TUBULAR ACIDOSIS

- Diabetes mellitus
- NSAIDs
- Cyclosporin
- RAS inhibition
- Spironolactone
- Amiloride
- Heparin
- Ketoconazole
- Lupus nephritis

METABOLIC ACIDOSIS

PATHOGENESIS AND CLASSIFICATION

LACTIC ACIDOSIS

TYPE A

- Cardiogenic shock
- Septic shock
- Hemorrhage
- Anemia
- Tissue hypoxia
- CO poisoning

TYPE B (ABSENCE OF TISSUE HYPOXIA)

- G6PD deficiency
- Metformin, Linezolide, Propofol
- Liver failure
- Malignancy

METABOLIC ACIDOSIS

SIGNS AND SYMPTOMS

CARDIOVASCULAR AND PULMONARY

Increased depth and rate of respiration, shortness of breath, arrythmia, reduced myocardial contractility

NEUROLOGIC

Lethargy, coma

MUSCULOSKELETAL

Children: impaired growth, rickets

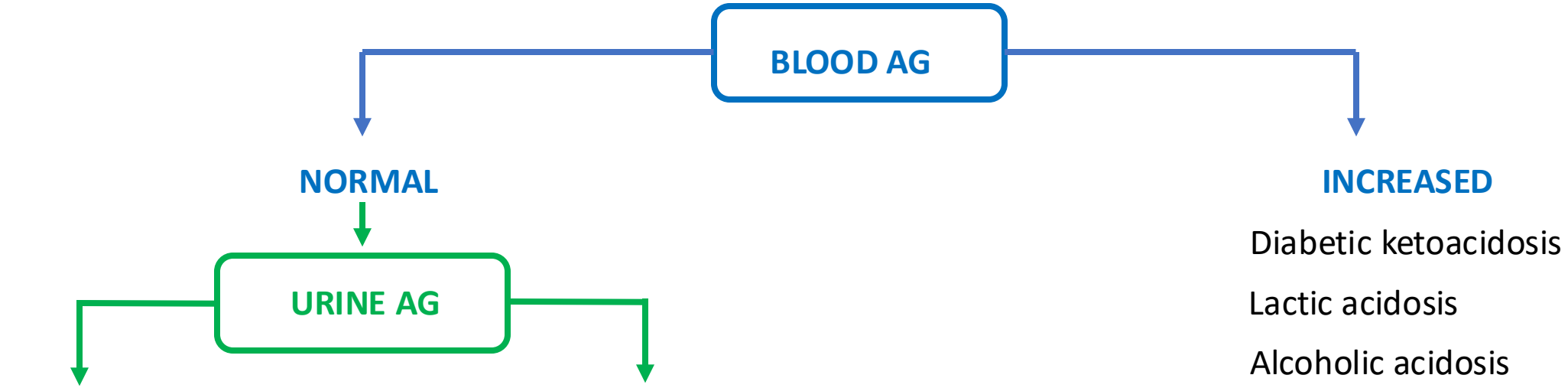
Adults: Osteitis fibrosa, osteomalacia, osteoporosis

UNDERLYING DISEASE

Diarrhea

METABOLIC ACIDOSIS

DIAGNOSTIC APPROACH



Diabetic ketoacidosis

Lactic acidosis

Alcoholic acidosis

Fasting

Methanol, ASA

<u>RENAL CAUSE</u>

RTA

<u>EXTRARENAL CAUSE</u>

Diarrhea

Fistula

Colostomies

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RESPIRATORY ACIDOSIS

CAUSES AND PATHOGENESIS

EXTRAPULMONARY DISEASE

A. INHIBITION OF THE RESPIRATORY CENTRE

1. ACUTE
   (a) Opiates, anesthetics, sedatives
   (b) CNS lesions

B. DISORDERS OF THE RESPIRATORY MUSCLES - CHEST WALL

1. ACUTE
   (a) Myasthenia
   (b) Aminoglycosides
   (c) Guillen-Barre Syndrome
2. CHRONIC
   (a) Kyphoscoliosis
   (b) Obesity
   (c) Poliomyelitis
   (d) Spinal cord injury

PULMONARY DISEASE

C. UPPER AIRWAY OBSTRACTION

1. ACUTE
   (a) Aspiration of foreign body or vomitus
   (b) Laryngospasm
   (c) Obstructive sleep apnea

D. DISORDERS AFFECTING GAS EXCHANGE ACROSS THE PULMONARY CAPILLARIES

1. ACUTE
   (a) Acute pulmonary edema
   (b) Acute Respiratory Distress Syndrome (ARDS)
   (c) Severe asthma, pneumonia
2. CHRONIC
   (a) Chronic Obstructive Pulmonary Disease (COPD)

RESPIRATORY ACIDOSIS

SIGNS AND SYMPTOMS

CENTRAL NERVOUS SYSTEM

1. ACUTE

   Headache, blurred vision, papilledema, restlessness, anxiety, delirium

2. CHRONIC (mild symptoms)

CARDIOVASCULAR SYSTEM

Arrythmias

Peripheral vasodilation

RESPIRATORY ACIDOSIS

DIAGNOSIS

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

ACUTE OR CHRONIC?

		pH	Primary disorder	Compensation
RESPIRATORY ACIDOSIS	ACUTE	↓	↑ PCO2 **10 mmHg**	↑ [HCO3-] **1 mEq/L**
	CHRONIC	↓	↑ PCO2 **10 mmHg**	↑ [HCO3-] **3.5 mEq/L**

EXTRAPULMONARY OR PULMONARY DISORDER?

Past history and clinical examination

$(A\text{-}a)\ O_2$ gradient $= 150 - 1.25 \times PCO_2 - PO_2$

Normal values = 5-10 mmHg in <30 years old

= 15-20 mmHg

Increased: Pulmonary disorder

RESPIRATORY ALKALOSIS

CAUSES - PATHOGENESIS

A. HYPOXIA

1. PULMONARY DISEASE
   (a) Pneumonia
   (b) Interstitial lung fibrosis
   (c) Emboli
   (d) Pulmonary edema
2. CONGESTIVE HEART FAILURE
3. HYPOTENSION
4. SEVERE ANEMIA
5. HIGH ALTITUDE RESIDENCE

B. PULMONARY DISEASE

C. STIMULATION OF THE RESPIRATORY CENTRE

1. PSYCHOGENIC VOLUNTARY HYPERVENTILATION
2. LIVER FAILURE
3. GRAM NEGATIVE SEPSIS
4. PREGNANCY, PROGESTERONE
5. NEUROLOGIC DISORDERS
   (a) Cerebrovascular accidents
   (b) Pontine tumors

D. MECHANICAL VENTILATION

RESPIRATORY ALKALOSIS

SIGNS AND SYMPTOMS

UNDERLYING DISEASE

NERVOUS SYSTEM

Light-headedness, altered consciousness, paresthesia of the extremities, cramps, carpopedal spasm

CARDIOVASCULAR SYSTEM

Supraventricular and ventricular arrythmias

RESPIRATORY ALKALOSIS

DIAGNOSIS

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

		pH	Primary disorder	Compensation
RESPIRATORY ALKALOSIS	ACUTE	↑	↓ PCO2 **10 mmHg**	↓ [HCO3-] **2 mEq/L**
	CHRONIC	↑	↓ PCO2 **10 mmHg**	↓ [HCO3-] **4 mEq/L**

CLINICAL CASE 5

A 24-year-old male patient presented at the Emergency Department of his local hospital reporting malaise, headache and mild dyspnea. He had a history of cigarette smoking but no significant past illnesses; physical examination, blood tests, chest X-ray and a head computed tomography (CT) scan were normal and on the same day he was discharged with symptomatic therapy. After four days he returned to the hospital with fever, productive cough and respiratory distress: a chest X-ray showed a left lung infiltrate and the patient was admitted to the Infectious Disease Department with a presumptive diagnosis of community-acquired pneumonia. Treatment with ceftriaxone and azythromycin was started but he rapidly developed a severe respiratory failure unresponsive to helmet-CPAP and required intubation and mechanical ventilation (MV). Vital signs at admission were: blood pressure 100/50 mmHg, pulse 110 bpm, body temperature 38.8 °C, body mass index (BMI) 24 kg/m^2. Laboratory values showed

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 5

BIOCHEMISTRY (BLOOD)		ABGs	
WBC (#/µl)	3200 (N<L)	pH	7
CRP (ng/ml)	0.9	HCO3- (mEq/L)	18
Ure (mg/dl)		PCO2 (mmHg)	109
Cre (mg/dl)		PO2 (mmHg)	44

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 5

$$pH = 6.10 + \log \frac{[HCO3-]}{0.03 \times PCO2}$$

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CRP (ng/ml)	0.9	HCO3- (mEq/L)	18
Ure (mg/dl)		PCO2 (mmHg)	109
Cre (mg/dl)		PO2 (mmHg)	44

[HCO3-] **1 mEq/L**

PCO2 **10 mmHg**

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 5

Bacterial cultures of blood, urine and tracheal aspirate were negative, as well as autoimmune tests. A nasal swab tested with real-time reverse transcription-polymerase chain reaction (rRT-PCR) was positive for H1N1 infection. Treatment with high-dose oseltamivir (300 mg/day) was immediately added to the initial empirical antibacterial therapy. Two days after, two other members of the patient's family developed high fever and productive cough without respiratory distress and were diagnosed with H1N1 infection.

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 5

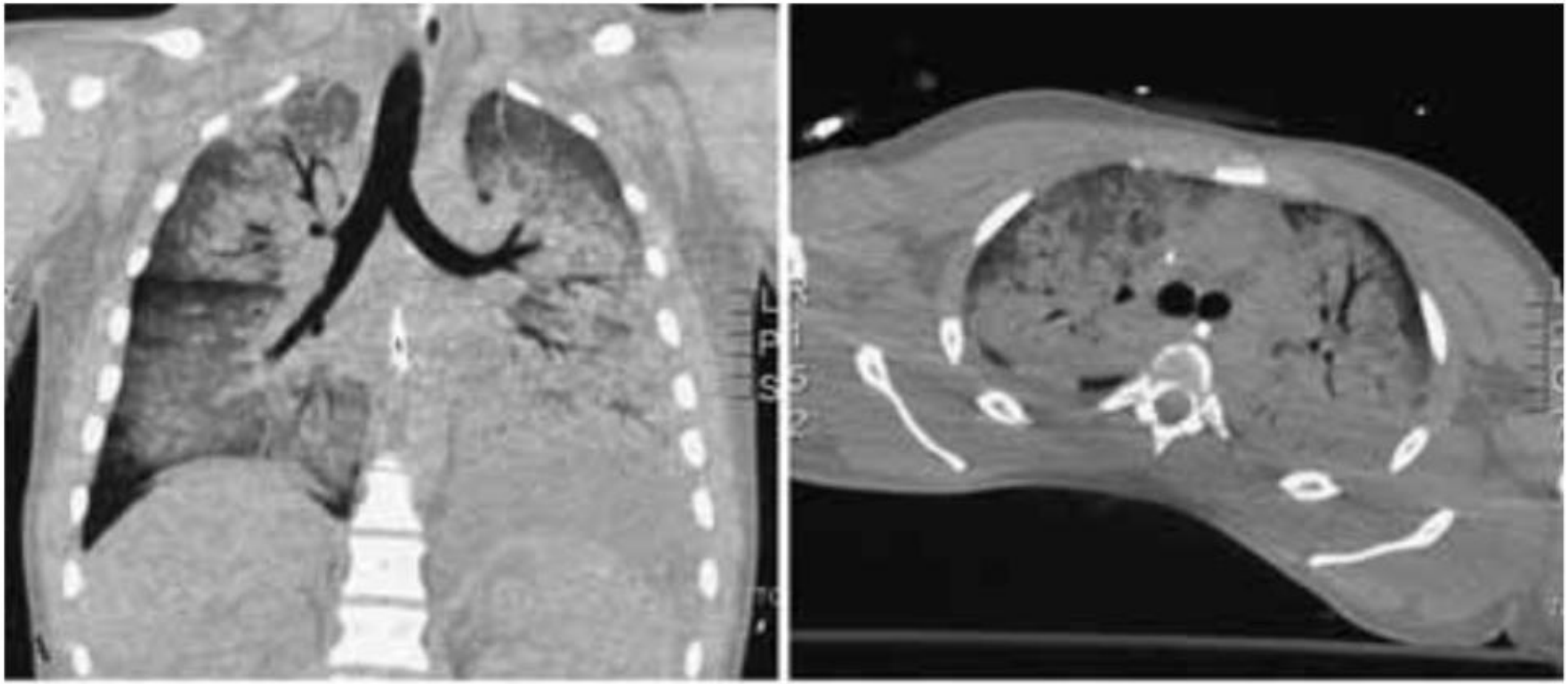


Figure 1.—A) Chest CT-scan obtained immediately after admission to our ICU: massive bilateral consolidation with air bronchogram are visible; B) Chest CT-scan obtained before discharge shows a partial resolution with residual areas of ground-glass and fibrotic strias.

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 5 - DISCUSSION

ACUTE RESPIRATORY ACIDOSIS

PATHOGENESIS

Disorder affecting gas exchange across the pulmonary capillaries (ARDS)

(A-a) O_2 gradient = 150 – 1.25P_{CO_2} – P_{O_2} = 58 mmHg **(>10, 24 yo)**

109 44

SIGNS AND SYMPTOMS

UNDERLYING DISEASE (H1N1 infection):

Malaise, fever, cough

NERVOUS SYSTEM

anxiety, headache, papilledema, restlessness

CARDIOVASCULAR SYSTEM (increased cardiac output, vasodilation)

warm, wet skin, tachycardia

Grasselli G et al. Min Anestesiologica 2009; 75:741

CLINICAL CASE 6

Chief complaint: Difficulty breathing and muscle weakness

History of Present Illness: The patient is a 38-year-old male who presented to the hospital with a complaint of difficulty breathing and muscle weakness. He reported that he has been experiencing fatigue, muscle weakness, and shortness of breath for several weeks, and it has been progressively getting worse. He also noticed that he has been breathing faster than usual and has been feeling lightheaded.

Medical History: The patient did not have any significant medical history.

Physical Examination: On examination, the patient appeared weak and had difficulty moving his limbs. He had a respiratory rate of 30 breaths per minute, and his oxygen saturation was 92% on room air. His blood pressure was 150/90 mmHg, and his heart rate was 110 beats per minute. His lungs were clear on auscultation, and his abdomen was soft and non-tender.

Diagnostic Tests: Blood tests revealed an elevated cortisol level and a low potassium level, which were consistent with Cushing's syndrome. An MRI of the brain showed a pituitary adenoma, which was the cause of the Cushing's syndrome. The patient was diagnosed

ChatGPT

CLINICAL CASE 6

ABGs	
pH	7.34
HCO3- (mEq/L)	37
PCO2 (mmHg)	67
PO2 (mmHg)	60

CLINICAL CASE 6

$$pH = 6.10 + \log \frac{[HCO3^-]}{0.03 \times PCO2}$$

ABGs	
pH	7.34
HCO3- (mEq/L)	37
PCO2 (mmHg)	67
PO2 (mmHg)	60

[HCO3-] **3.5 mEq/L**

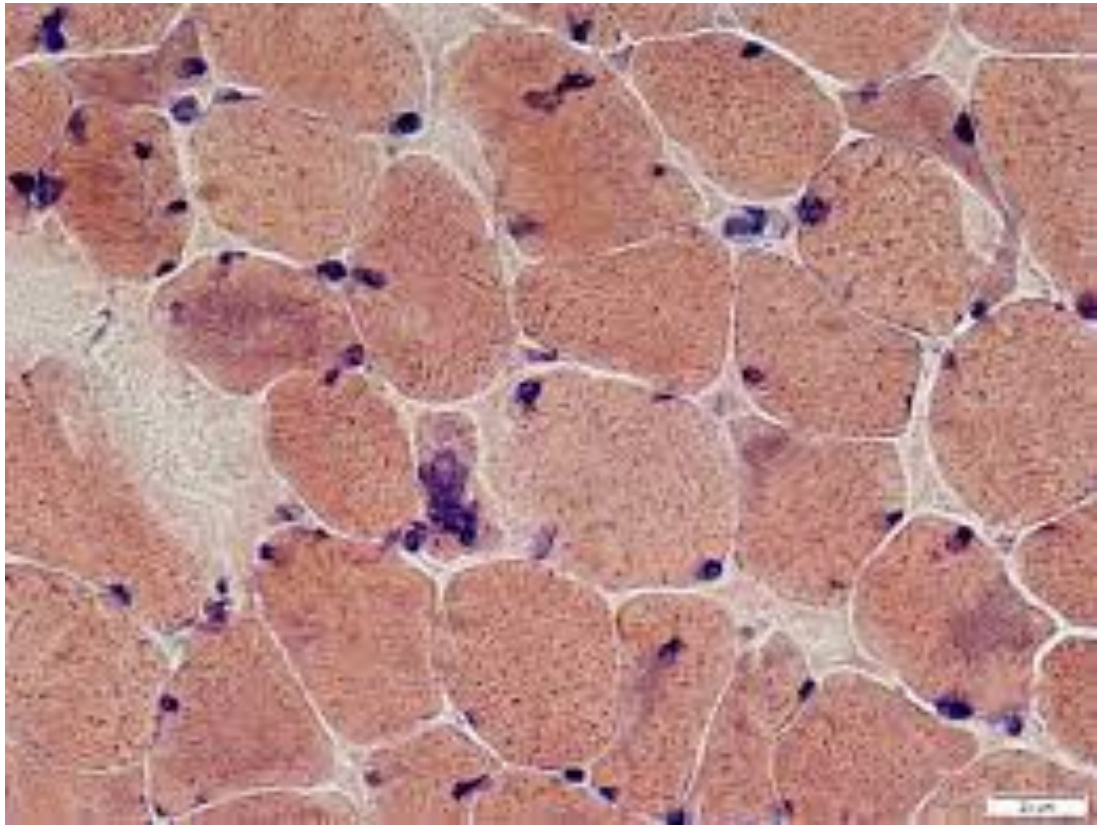
PCO2 **10 mmHg**

(A-a) O2 gradient = 150 - 1.25PCO2 - PO2 = **6 mmHg**

67 60

EXTRAPULMONARY DISORDER

CLINICAL CASE 6



Muscle biopsy: muscle atrophy

https://neuromuscular.wustl.edu/pathol/remm.htm

CLINICAL CASE 6 - DISCUSSION

CHRONIC RESPIRATORY ACIDOSIS

PATHOGENESIS

Chronic disorder of the respiratory muscles

67 60

(A-a) O2 gradient = 150 – 1.25PCO_2 – PO_2 = 6 mmHg **(<20, 38 yo)**

SIGNS AND SYMPTOMS

UNDERLYING DISEASE

NERVOUS SYSTEM

Absence of symptomatology (chronic disease)

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efrangou@outlook.com.gr