

Acid-Base Basics

Jeffrey H. William, MD

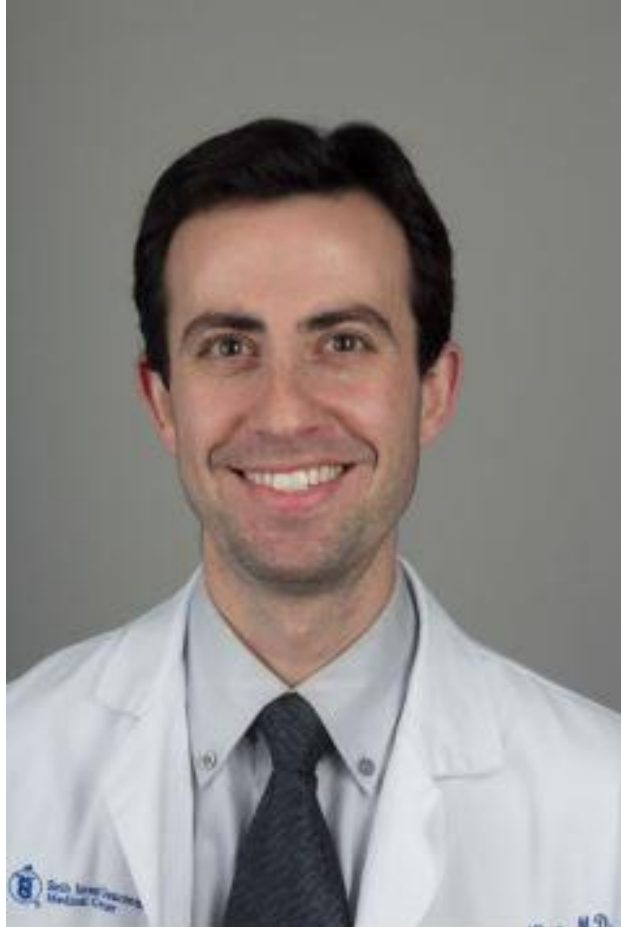
Assistant Professor of Medicine, Harvard Medical School

Associate Program Director, BIDMC Renal Fellowship

Firm Chief, Tullis Firm, BIDMC Internal Medicine Residency

X: @jwilliamMD

Jeffrey H. William, MD



- MD, Tufts University School of Medicine
- Residency, Beth Israel Deaconess Medical Center
- Fellowship, Beth Israel Deaconess Medical Center
- Assistant Professor, Harvard Medical School
- Associate Program Director, Nephrology Fellowship, Beth Israel Deaconess Medical Center
- Chief, Tullis Firm, BIDMC IM Residency

Disclosures

- None

Why I care about acid-base disturbances (and you should too...)

- Discerning which acid-base abnormalities are occurring in your patients enables you to provide **better patient care**
- There are often multiple processes happening at the same time and a systematic approach may **reveal underlying etiologies** that could otherwise go unnoticed
- It's actually kind of fun...if you're the sort of person who comes to a CME course to learn about kidneys

After this talk, you will be able to...

- ...accurately diagnose acid-base abnormalities in the acute care setting
- ...utilize an organized approach to the diagnosis and treatment of any acid-base abnormality and its etiologies
- ...uncover previously “hidden” acid-base disorders using your newly acquired acid-base skills

Keeping it simple

- There are LOTS of ways to make acid-base more complicated!
 - Henderson-Hasselbalch equation
 - Carbonic acid equilibrium
 - Stewart acid-base method
 - ...and more!
- **There are only 2 ways to create acid-base disturbances**
 - Metabolic (changes in H^+ / HCO_3^- balance)
 - Respiratory (changes in pCO_2 level)
- **There are only 2 directions the pH can go***
 - Down (acidemia)
 - Up (alkalemia)
 - *Neither! (pH in normal range)
- **We will only discuss 1 compensation rule (Winters formula)**
 - It's the most reliable one
 - You can look up the rest...

The *simple* 4-step approach

- 1) Acidemia or alkalemia? (pH)
- 2) Primary process – metabolic or respiratory? (HCO_3^- / pCO_2)
- 3) Secondary process / *compensation* (HCO_3^- / pCO_2)
- 4) Is there an anion gap?
 - If so, consider if there is an *additional* metabolic process (“ $\Delta \text{AG} / \Delta \text{HCO}_3^-$ ”)

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with increased urinary frequency, increased thirst, and fevers. Urinalysis is suggestive of a UTI while cultures are pending. She appears uncomfortable on exam.

130	100	30	446
3.6	12	1.3	

Na ⁺	Cl ⁻	BUN	Gluc
K ⁺	HCO ₃ ⁻	Cr	

7.27 / 28 / 88

pH / pCO₂ / pO₂

Audience response question #1

Which of the following best describes this patient's acid-base disturbance?

- a) Anion-gap metabolic acidosis
- b) Anion-gap metabolic acidosis AND respiratory acidosis
- c) Anion-gap metabolic acidosis AND non-gap metabolic acidosis
- d) Anion-gap metabolic acidosis, non-gap metabolic acidosis, and respiratory alkalosis
- e) Non-gap metabolic acidosis and respiratory alkalosis

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with increased urinary frequency, increased thirst, and fevers. Urinalysis is suggestive of a UTI while cultures are pending. She appears uncomfortable on exam.

130	100	30	446	7.27 / 28 / 88
3.6	12	1.3		
Na ⁺	Cl ⁻	BUN	Gluc	pH / pCO ₂ / pO ₂
K ⁺	HCO ₃ ⁻	Cr		

4-step approach

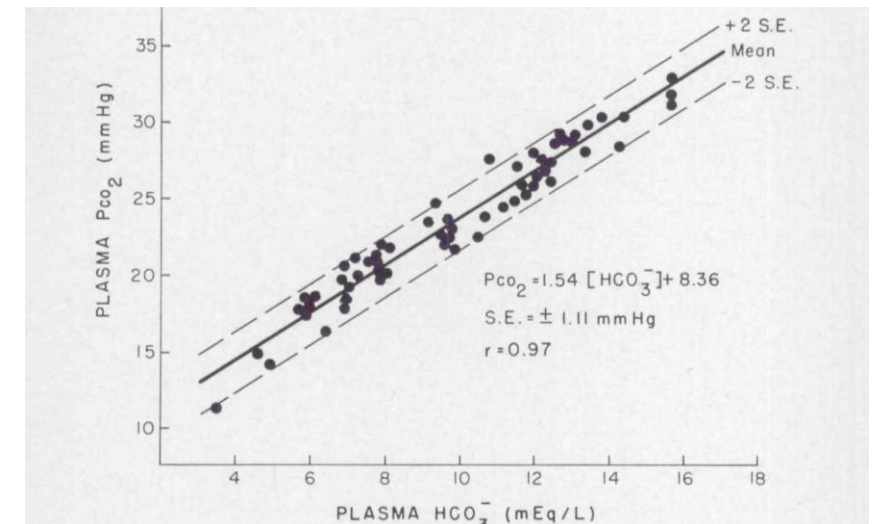
- 1) pH = 7.27 → **ACIDEMIA**
- 2) Low HCO_3^- supports the acidosis
METABOLIC
- 3) Is the pCO_2 change appropriate?
Expected $\text{pCO}_2 = 26 \pm 2 \rightarrow \text{YES}$
- 4) Anion gap = $\text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-) = 18 = \text{HIGH}$
 $\Delta \text{AG} = 18 - 12 = 6$ (normal anion gap = 12)
 $\Delta \text{HCO}_3^- = 24 - 12 = 12$ (normal $\text{HCO}_3^- = 24$)
 $\Delta \text{AG} / \Delta \text{HCO}_3^- = 6 / 12 = 0.5$
 $<1 = \text{add'l non-gap metabolic acidosis, OR}$
 $>2 = \text{add'l metabolic alkalosis}$

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with increased urinary frequency, increased thirst, and fevers. Urinalysis is suggestive of a UTI while cultures are pending. She appears uncomfortable on exam.

130	100	30	446	7.27 / 28 / 88
3.6	12	1.3		
Na ⁺	Cl ⁻	BUN	Gluc	pH / pCO ₂ / pO ₂
K ⁺	HCO ₃ ⁻	Cr		

“Winters formula”

$$\text{Exp pCO}_2 = 1.5 (\text{HCO}_3^-) + 8 \pm 2$$



Anion gap and non-gap metabolic acidosis etiologies

AGMA (gain of H⁺ and anion)

- Lactic acids (D and L-lactate)
- Ketoacids (diabetic, EtOH, starvation)
- Organic acids (from severe renal failure/uremia)
- Toxic alcohols (methanol, glycols)

“GOLD MARK”

GOLD MARK: an anion gap mnemonic for the 21st century

CORRESPONDENCE | VOLUME 372, ISSUE 9642, P892, SEPTEMBER 13, 2008

- G:** glycols (propylene glycol and ethylene glycol)
- O:** 5-oxoproline (associated with acetaminophen use)
- L:** L-lactate
- D:** D-lactate (short bowel syndrome)
- M:** methanol
- A:** aspirin
- R:** renal failure
- K:** ketoacidosis (diabetic/alcohol/starvation)

Intoxications and the serum osmolal gap

Serum osmolality can be **measured** by the lab and **calculated** by you!

$$\text{Calculated } S_{osm} = 2 [Na+] + [glucose] / 18 + [BUN] / 2.8$$

$$\text{Serum osmolal gap} = \text{Measured } S_{osm} - \text{Calculated } S_{osm}$$

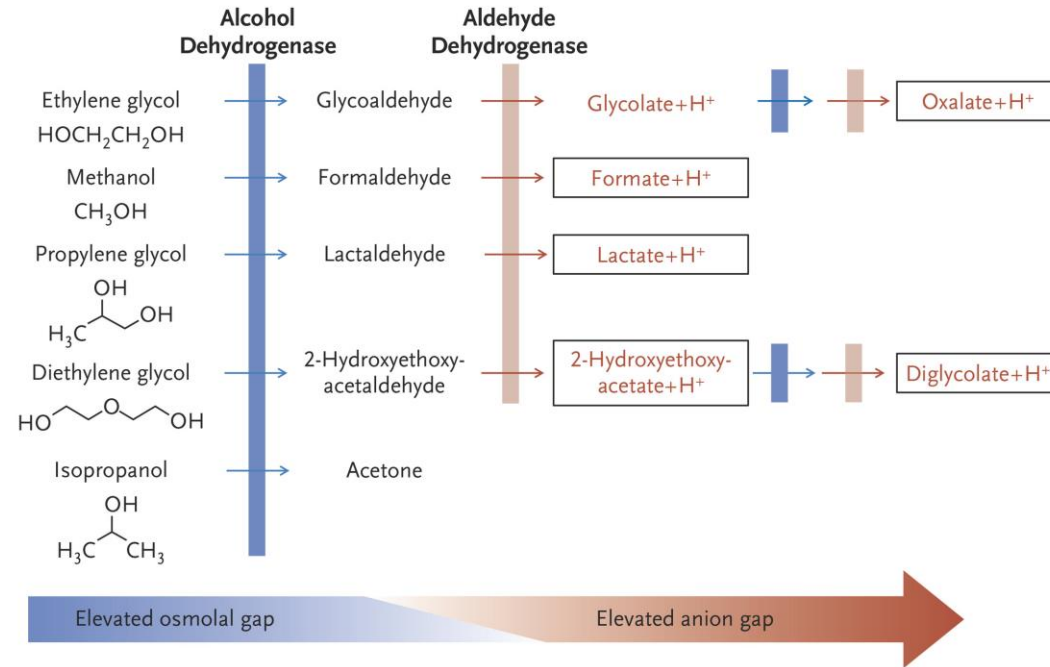
Similar to the anion gap, this difference reveals an **unmeasured osmole** that may be contributing to the clinical picture (normal 0-10)

Using the anion gap + osmolal gap in diagnosing acute intoxications

Anion gap	Osmolal gap	Intoxication	Clues to diagnosis
High	Normal	Salicylates	Concurrent respiratory alkalosis, tinnitus/hearing loss
High	High	Methanol	Alcoholic “feter” but EtOH negative, papilledema
		Ethylene glycol	Lack of feter, CaOx crystalluria
		Propylene glycol	High-dose IV lorazepam + lactic acidosis
		Ethanol	
Normal	High	Isopropanol	Clinically similar to EtOH intoxication, with “fruity” acetone breath, ketosis

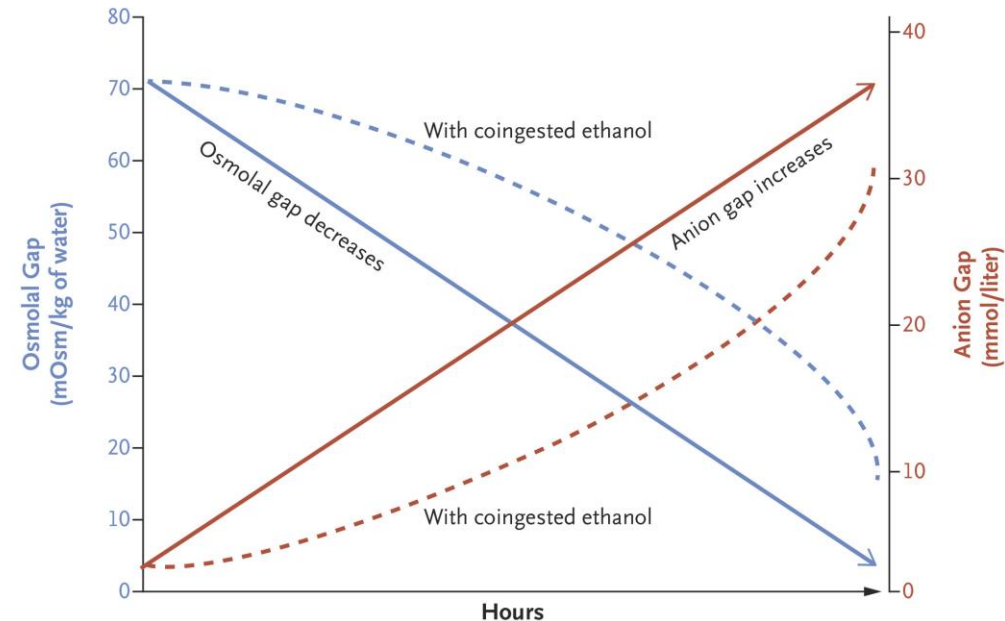
Metabolism of toxic alcohols

A Metabolic Pathways of Toxic Alcohols



Inverse relationship of anions and osmoles

B Time Course of Changes in the Osmolal and Anion Gaps



Anion gap and non-gap metabolic acidosis etiologies

AGMA (gain of H^+ and anion)

- Lactic acids
- Toxic alcohols
- Ketoacids
- Organic acids (severe renal failure/uremia)

“GOLD MARK”

NAGMA

- *Gain of H^+ (and a measured anion)*
 - **Normal saline!**
 - Distal RTA (impaired urinary acidification)
- *Loss of HCO_3^-*
 - **Diarrhea**
 - Acetazolamide (and other carbonic anhydrase inhibitors)
 - Proximal RTA
 - GI fistulae
 - Uretero-colonic
 - Pancreatic

You diagnose this 26-year-old woman with **diabetic ketoacidosis**, without other ingestions. After treating her with **4L of normal saline** and an insulin drip, she reveals that she has also had **significant diarrhea**. Her labs are re-checked.

135	110	30	243
2.9	16	1.1	

Na ⁺	Cl ⁻	BUN	Gluc
K ⁺	HCO ₃ ⁻	Cr	

7.38 / 28 / 88

pH / pCO₂ / pO₂

Audience response question #2

Which of the following best describes this patient's acid-base disturbance *after treatment*?

- a) Anion-gap metabolic acidosis
- b) Non-gap metabolic acidosis AND respiratory acidosis
- c) Anion-gap metabolic acidosis AND respiratory acidosis
- d) Anion-gap metabolic acidosis, non-gap metabolic acidosis, and respiratory alkalosis
- e) Non-gap metabolic acidosis and respiratory alkalosis

You diagnose this 26-year-old woman with **diabetic ketoacidosis**, without other ingestions. After treating her with **4L of normal saline** and an insulin drip, she reveals that she has also had **significant diarrhea**. Her labs are re-checked.

135	110	30	243	7.38 / 28 / 88
2.9	16	1.1		
Na ⁺	Cl ⁻	BUN	Gluc	pH / pCO ₂ / pO ₂
K ⁺	HCO ₃ ⁻	Cr		

Practice makes better...

- 1) pH = 7.38 → ***"NORMAL"*** (??)
- 2) Low HCO_3^- → Metabolic acidosis
Low pCO_2 → Respiratory alkalosis
- 3) Compensations NEVER result in normal pH! Must be 2 processes.
- 4) Anion gap = $\text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-) = 9 = \text{Normal}$
Non-anion gap metabolic acidosis

You diagnose this 26-year-old woman with **diabetic ketoacidosis**, without other ingestions. After treating her with **4L of normal saline** and an insulin drip, she reveals that she has also had **significant diarrhea**. Her labs are re-checked.

135	110	30	243	7.38 / 28 / 88
2.9	16	1.1		
Na ⁺	Cl ⁻	BUN	Gluc	pH / pCO ₂ / pO ₂
K ⁺	HCO ₃ ⁻	Cr		

A hidden respiratory alkalosis?

The pCO_2 was identical in both of these scenarios...

$\text{pH } 7.38$ / $\text{pCO}_2 28$ / $\text{pO}_2 88$

So why didn't we detect the respiratory alkalosis upon presentation?

With her initial dual-etiology metabolic acidosis, the respiratory alkalosis was masked as an *appropriate physiologic compensation*.

After her DKA was treated, the same respiratory alkalosis process was revealed to be *pathophysiologic* (a secondary process that requires work-up)

Respiratory alkalosis etiologies

Hyperventilation

- Pneumonia
- Pulmonary edema
- Pulmonary embolism
- Drugs (i.e., salicylates)
- Pregnancy
- Cirrhosis

Now...what if she presented like this?

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with **altered mental status**. Urinalysis is suggestive of a UTI while cultures are pending. She appears **somnolent** on exam.

These chemistries are the same as the original case!

130	100	30	446
3.6	12	1.3	
Na ⁺	Cl ⁻	BUN	Gluc
K ⁺	HCO ₃ ⁻	Cr	

This ABG is NOT the same!

7.16 / 35 / 88

pH / pCO₂ / pO₂

Audience response question #3

Which of the following best describes this patient's acid-base disturbance?

- a) Anion-gap metabolic acidosis
- b) Anion-gap metabolic acidosis, non-gap metabolic acidosis, and respiratory acidosis
- c) Anion-gap metabolic acidosis AND respiratory acidosis
- d) Anion-gap metabolic acidosis AND non-gap metabolic acidosis
- e) Non-gap metabolic acidosis and respiratory acidosis

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with **altered mental status**. Urinalysis is suggestive of a UTI while cultures are pending. She appears **somnolent** on exam.

These chemistries are the same as the original case!

130	100	30	446
3.6	12	1.3	
Na ⁺	Cl ⁻	BUN	Gluc
K ⁺	HCO ₃ ⁻	Cr	

This ABG is NOT the same!

7.16 / 35 / 88

pH / pCO₂ / pO₂

Why is this case different?

1) $\text{pH} = 7.16 \rightarrow \text{ACIDEMIA}$

2) Low HCO_3^- supports the acidosis
METABOLIC

3) Is the pCO_2 change appropriate?
Expected $\text{pCO}_2 = 26 \pm 2 \rightarrow \text{NO!}$
Actual $\text{pCO}_2 = 35 \rightarrow \text{respiratory acidosis}$

4) Anion gap = $\text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-) = 18 = \text{HIGH}$
 $\Delta \text{AG} = 18 - 12 = 6 \rightarrow \text{normal anion gap} = 12$
 $\Delta \text{HCO}_3^- = 24 - 12 = 12 \rightarrow \text{normal } \text{HCO}_3^- = 24$
 $\Delta \text{AG} / \Delta \text{HCO}_3^- = 6 / 12 = 0.5$
 $< 1 = \text{add'l } \text{non-gap metabolic acidosis}$

26-year-old woman (she/her) with type 1 diabetes mellitus presents to the hospital with **altered mental status**. Urinalysis is suggestive of a UTI while cultures are pending. She appears **somnolent** on exam.

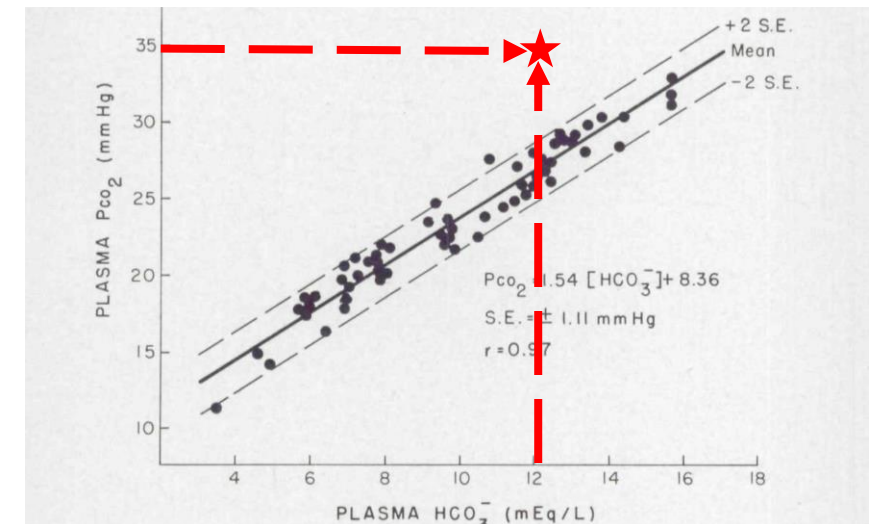
These chemistries are the same as the original case!

130	100	30	446	7.16 / 35 / 88
3.6	12	1.3		
Na ⁺	Cl ⁻	BUN	Gluc	pH / pCO ₂ / pO ₂
K ⁺	HCO ₃ ⁻	Cr		

This ABG is NOT the same!

“Winters formula”

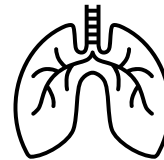
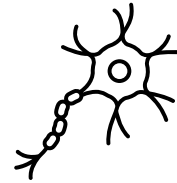
$$\text{Exp pCO}_2 = 1.5 (\text{HCO}_3^-) + 8 \pm 2$$



Respiratory acidosis etiologies

Hypoventilation

- “Can’t breathe”
 - CNS depression
- “Won’t breathe”
 - Neuromuscular disorder
 - Mechanical obstruction
- “Can’t breathe enough”
 - COPD

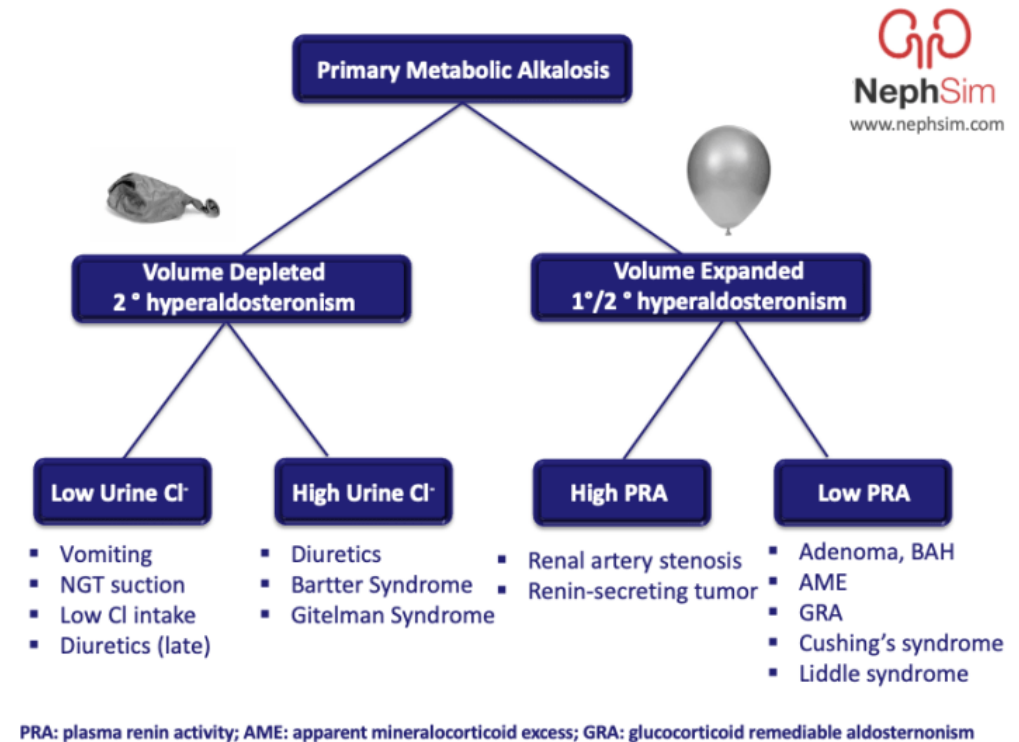


(Almost) all of acid-base...in a single case

- Anion-gap metabolic acidosis – **diabetic ketoacidosis**
- Non-gap metabolic acidosis – **concurrent diarrhea + normal saline**
- Respiratory alkalosis – **initially appropriate compensation, then pathophysiologic**
- Respiratory acidosis - **respiratory failure (i.e., sign of fatigue)**

Metabolic alkalosis

- Less common because our kidneys can compensate for excess bicarbonate easily through urinary excretion
- Comprised of 2 phases
 - **Generation phase** – the inciting event
 - Vomiting
 - Diuretics
 - Excess calcium carbonate intake
 - Hyperaldosteronism
 - **Maintenance phase** – an ongoing process interrupts the kidney's ability to excrete bicarbonate
 - AKI
 - Hypovolemia
 - Hyperaldosteronism (or apparent mineralocorticoid excess)
- Management of the underlying etiologies allows for normal kidney function to restore acid-base balance



Take-Home points

- A simple yet systematic approach to acid-base disturbances will inform diagnosis and treatment of a complex patient
- High anion gap metabolic acidoses represent a unique opportunity to quickly consider a limited differential diagnosis and provide life-saving and timely treatment
- Revealing “hidden” acid-base disorders helps inform further history taking and eventual clinical management

After this talk, you will be able to...

- ...accurately diagnose acid-base abnormalities in the acute care setting
- ...utilize an organized approach to the diagnosis and treatment of any acid-base abnormality and its etiologies
- ...uncover previously “hidden” acid-base disorders using your newly acquired acid-base skills

