Project: Ghana Emergency Medicine Collaborative

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Objectives

- Understand importance of maintaining acid-base balance.
- Understand different ways the body maintains this balance.
- Develop differential diagnoses based on the acid-base disorder.
- Calculate primary acid-base disorders.
- Calculate mixed acid-base disorders.

Maintaining Acid-Base Balance

- Controlled by the Lungs, Kidneys and Buffers
- Disrupted by Vomiting, Diarrhea, Respiratory Failure, Kidney Failure, Infections and Ingestions

Principles of Acid-Base Disorders

- Kidneys, Lungs and Buffers maintain serum pH between 7.36 and 7.44
- Blood pH is determined by the ratio of serum bicarbonate concentration ([HCO_3^-]) and partial pressure of CO_2 (Pa_{CO_2})

Principles of Acid-Base Disorders

- Metabolic acid-base disorders and secondary metabolic compensation alter [HCO_3^-]
- Respiratory acid-base disorders and secondary respiratory compensation alter (Pa_{CO_2})

Principles of Acid-Base Disorders

- Subtle changes in pH cause large shifts in acid-base pair
- Determines how drugs disperse and bind and how enzymes react
- Proteins function within narrow spectrum of pH

Principles of Acid-Base Disorders

- Acidemia: serum pH < 7.36
- Alkalemia: serum pH > 7.44
- Acidosis: pathologic process that lowers $[HCO_3^-]$ or raises Pa_{CO_2}
- Alkalosis: pathologic process that raises $[HCO_3^-]$ or lowers Pa_{CO_2}

Physiologic Buffers

- Oppose significant changes in pH
- Bicarbonate/Carbonic acid system
  - Located primarily in RBCs
  - $H^+ + HCO_3^- \Leftrightarrow H_2CO_3 \Leftrightarrow H_2O + CO_2$
- Intracellular protein buffers
- Phosphate buffers
  - Located within bone

Pulmonary Compensation

- Peripheral chemoreceptors in the carotid bodies and central chemoreceptors in the medulla change minute ventilation
  - Decreased pH → increased minute ventilation → decreased Pa_{CO_2}
- Compensatory processes return pH toward normal over many hours, but do not fully correct pH

Anion Gap

- Estimates unmeasured anions in plasma (albumin)
- AG = Na^+ - (Cl^- + HCO_3^-)
- Normal = 12 +/- 3 mEq/L
- ΔG will be used in mixed disorders

Scenario 1

- A 38 year-old man comes in to the Emergency Department after being involved in a rollover motor vehicle crash. He is complaining of right sided chest pain and difficulty breathing. He is taking shallow breaths. He has symmetric breath sounds. He is very tender over the right upper chest. What acid-base disorder do you suspect?

Respiratory Acidosis

- Decreased pH due to pulmonary CO_2 retention
- Excess H_2CO_3 production leads to acidemia
  - $H^+ + HCO_3^- \Leftrightarrow H_2CO_3 \Leftrightarrow H_2O + CO_2$
- Acute respiratory acidosis has normal HCO_3^-
- Chronic respiratory acidosis has elevated HCO_3^- due to renal retention

Respiratory Acidosis

- What are some of the causes of Respiratory Acidosis?

Respiratory Acidosis

- What are some of the causes of Respiratory Acidosis?
- Anything that causes your minute ventilation to decrease

Respiratory Acidosis

- Airway
  - Obstruction, aspiration
- Drug-induced CNS depression
  - Alcohol, narcotics, IV sedation
- CNS origin
  - Myasthenia gravis, CNS injury, Guillain-Barré
- Pulmonary disease
  - Pneumonia, edema, COPD/emphysema
- Thoracic cage
  - Pneumothorax, flail chest

Respiratory Acidosis Compensation

- Would you expect the [HCO_3^-] to increase or decrease when Pa_{CO_2} increases?

Respiratory Acidosis Compensation

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

Respiratory Acidosis Compensation

- Acute
  - HCO_3^- production from intracellular proteins
  - [HCO_3^-] increases 1mEq/L for every 10mm Hg rise in Pa_{CO2}
- Chronic
  - Renal retention of HCO_3^-
  - [HCO_3^-] increases 3.5mEq/L for every 10mm Hg rise in Pa_{CO2}
  - Takes 12 hours to many days for renal retention of HCO_3^-
  - Nearly normalizes pH

Management

- Correct the minute ventilation
  - Establish airway
  - Re-expand the lung
  - Correct the CNS disease
  - Bronchodilators
  - Antibiotics
- Chronic respiratory acidosis
  - Progressive decrease in sensitivity to CO_2 by respiratory centers
  - Cautious use of oxygen, because may lose hypoxic respiratory drive and develop CO_2 narcosis

What is this Acid-Base Disorder?

- 25 year-old male, heroin overdose
  - pH 7.10 Pa_{CO_2} 80 HCO_3^- 24

What is this Acid-Base Disorder?

- 25 year-old male, heroin overdose
  - pH 7.10 Pa_{CO_2} 80 HCO_3^- 24
  - Acidemic, Pa_{CO_2} is elevated, acute change
  - Acute respiratory acidosis ($[HCO_3^-]$ unchanged)

What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.32 Pa_{CO_2} 70 HCO_3^- 35

What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.32 Pa_{CO_2} 70 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis

What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.32 Pa_{CO_2} 70 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis
  - Is the bicarb what you would expect?

What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.32 Pa_{CO_2} 70 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis
  - Is the bicarb what you would expect?
  - Pa_{CO_2} increased by 30, so would expect [HCO_3^-] to increase by 10.5 (3.5 x 3)

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- 55 year-old man with COPD
  - pH 7.32 Pa_{CO_2} 70 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis
  - Is the bicarb what you would expect?
  - Pa_{CO_2} increased by 30, so would expect [HCO_3^-] to increase by 10.5 (3.5 x 3)
  - Yes, it is what you would expect

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What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.23 Pa_{CO_2} 90 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis
  - Is the bicarb what you would expect?
  - Pa_{CO_2} increased by 50, so would expect [HCO_3^-] to increase by 17.5 (3.5 x 5)

What is this Acid-Base Disorder?

- 55 year-old man with COPD
  - pH 7.23 Pa_{CO_2} 90 HCO_3^- 35
  - Acidemic, Pa_{CO_2} is elevated → respiratory acidosis
  - Is the bicarb what you would expect?
  - Pa_{CO_2} increased by 50, so would expect [HCO_3^-] to increase by 17.5 (3.5 x 5)
  - No, the bicarb has not compensated appropriately yet, indicating an acute respiratory acidosis on a chronic respiratory acidosis

Scenario 2

- An 18 year-old man comes in to the Emergency Department and is extremely anxious. He says his fingers and toes are tingling and his hands are cramping. He is breathing approximately 70 times per minute. Assuming he did not ingest anything, what acid-base disorder do you suspect?

Respiratory Alkalosis

- Increased minute ventilation leads to decreased Pa_{CO_2} and alkalosis
- Acute respiratory alkalosis has normal HCO_3^-
- Chronic respiratory alkalosis has decreased HCO_3^- due to renal compensation

Respiratory Alkalosis

- What causes Respiratory Alkalosis?

Respiratory Alkalosis

- What causes Respiratory Alkalosis?
- Anything that increases your minute ventilation

Respiratory Alkalosis

- Hypoxia-mediated hyperventilation
  - High altitude, severe anemia, ventilation-perfusion mismatch
- CNS mediated
  - Psychogenic, CVA, increased ICP (tumor/trauma)
- Pharmacologic
  - Salicylates, caffeine, vasopressors, thyroxine
- Pulmonary
  - Pneumonia, PE, mechanical hyperventilation, atelectasis
- Hepatic
  - Encephalopathy

Respiratory Alkalosis Compensation

- Would you expect the [HCO_3^-] to increase or decrease when Pa_{CO_2} decreases?

Respiratory Alkalosis Compensation

- Acute
  - Plasma [HCO_3^-] is lowered by 2mEq/L for every 10-mm Hg decrease in Pa_{CO_2}
- Chronic
  - Plasma [HCO_3^-] is lowered by 5mEq/L for every 10-mm Hg decrease in Pa_{CO_2}

What is the Acid-Base Disorder?

- 62 year-old woman with pneumonia for 1 week
  - pH 7.46 Pa_{CO_2} 20 HCO_3^- 14

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  - Is the bicarb what you would expect?

What is the Acid-Base Disorder?

- 62 year-old woman with pneumonia for 1 week
  - pH 7.46 Pa_{CO_2} 20 HCO_3^- 14
  - Alkalemic, Pa_{CO_2} is decreased → respiratory alkalosis
  - Is the bicarb what you would expect?
  - Yes, Pa_{CO_2} decreased by 20, so would expect bicarb to decrease by 10 in chronic respiratory alkalosis

Scenario 3

- An 22 year-old man with diabetes comes in after vomiting for 3 days. His sugars have been “high” at home. He appears extremely dry and is moaning without answering questions. What acid-base disorder do you suspect?

Metabolic Acidosis

- Acidemia created by increase in [H^+] or decrease in [HCO_3^-]
- Compensated for by hyperventilation to reduce Pa_{CO_2}

Metabolic Acidosis

- Divided into elevated Anion Gap and normal Anion Gap
- AG = Na^+ - (Cl^- + HCO_3^-)
- Normal = 12 +/- 3 mEq/L

Anion Gap Metabolic Acidosis

- MUDPILES
  - Methanol
  - Uremia
  - DKA
  - Propylene glycol, Paraldehyde
  - Infection, Iron, Isoniazid
  - Lactic acidosis
  - Ethylene glycol, Ethanol
  - Salicylates

Non-Anion Gap Metabolic Acidosis

- GI HCO_3^- loss
  - Diarrhea, colostomy, ileostomy
- Renal HCO_3^- loss
  - Renal tubular acidosis
  - Hyperparathyroidism
- Ingestion
  - Acetazolamide, Calcium Chloride, Magnesium Sulfate

Metabolic Acidosis

- Compensation (Winter's Formula)
  - $Pa_{CO_2} = 1.5 \times [HCO_3^-] + 8 +/- 2$

    $= 1.5 \times [HCO_3^-] + 6 \text{ or } 10$

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14
  - Acidemic, Pa_{CO_2} is decreased → metabolic acidosis

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14
  - Acidemic, Pa_{CO_2} is decreased → metabolic acidosis
  - What is the anion gap?
    - Na^+ 140 Cl^- 100 HCO_3^- 14

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14
  - Acidemic, Pa_{CO_2} is decreased → metabolic acidosis
  - What is the anion gap?
    - Na^+ 140 Cl^- 100 HCO_3^- 14
- Anion Gap = 26
- Why is this elevated?

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14
  - Acidemic, Pa_{CO_2} is decreased → metabolic acidosis
  - Is the Pa_{CO_2} what you would expect?

What is the Acid-Base Disorder?

- 23 year-old woman with seizure for 90 minutes.
  - pH 7.24 Pa_{CO_2} 36 HCO_3^- 14
  - Acidemic, Pa_{CO_2} is decreased → metabolic acidosis
  - Is the Pa_{CO_2} what you would expect?
  - Pa_{CO_2} = (1.5 x 14) + 8 +/- 2 = 27 – 31
  - You would expect the Pa_{CO_2} to be lower

Metabolic Acidosis

- Treatment
  - Treat the underlying condition and the pH will gradually normalize

Scenario 4

- An 29 year-old pregnant woman has been vomiting for 1 week. What acid-base disorder do you suspect?

Metabolic Alkalosis

- Alkalemia created by decrease in $[H^+]$ or increase in $[HCO_3^-]$
- Compensated for by hypoventilation to increase Pa_{CO_2}

Metabolic Alkalosis

- Volume-Contracted
  - Vomiting/gastric suction
  - Diuretics
- Normal Volume / Volume-Expanded
  - Severe potassium depletion
  - Hyperaldosteronism
  - Cushing's syndrome

Metabolic Alkalosis

- Treatment
  - Treat the underlying disorder
  - Correct potassium if needed
  - Give fluids if urine Cl^- < 10mEq/L
  - Consider acetazolamide if edematous, will increase HCO_3^- secretion

Metabolic Alkalosis

- Compensation
  - $Pa_{CO_2} = 0.9 \times [HCO_3^-] + 15$

What is the Acid-Base Disorder?

- 29 year-old pregnant woman who is vomiting.
  - pH 7.58 Pa_{CO_2} 48 HCO_3^- 40

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- 29 year-old pregnant woman who is vomiting.
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What is the Acid-Base Disorder?

- 29 year-old pregnant woman who is vomiting.
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  - Is the Pa_{CO_2} what you would expect?

What is the Acid-Base Disorder?

- 29 year-old pregnant woman who is vomiting.
  - pH 7.58 Pa_{CO_2} 48 HCO_3^- 40
  - Alkalemic, Pa_{CO_2} is increased → metabolic alkalosis
  - Is the Pa_{CO_2} what you would expect?
  - Pa_{CO_2} = (0.9 x 40) + 15 = 51

Mixed Disorders

- Sometimes more than one acid-base disorder is present
- Metabolic and respiratory processes can both be present
- Metabolic acidosis and alkalosis can both be present
- Respiratory acidosis cannot be present with respiratory alkalosis

Mixed Disorders

- If the pH is near normal, and the Pa_{CO_2} and/or the [HCO_3^-] is abnormal, assume a mixed disorder


What is the pH?
>7.44
<7.36
Alkalosis
Acidosis
P_{CO_2} < 40 then respiratory alkalosis
P_{CO_2} > 40 then metabolic alkalosis
P_{CO_2} > 40 then respiratory acidosis
P_{CO_2} < 40 then metabolic acidosis
Calculate anion gap
$Na^+ - (Cl^- + CO_2)$

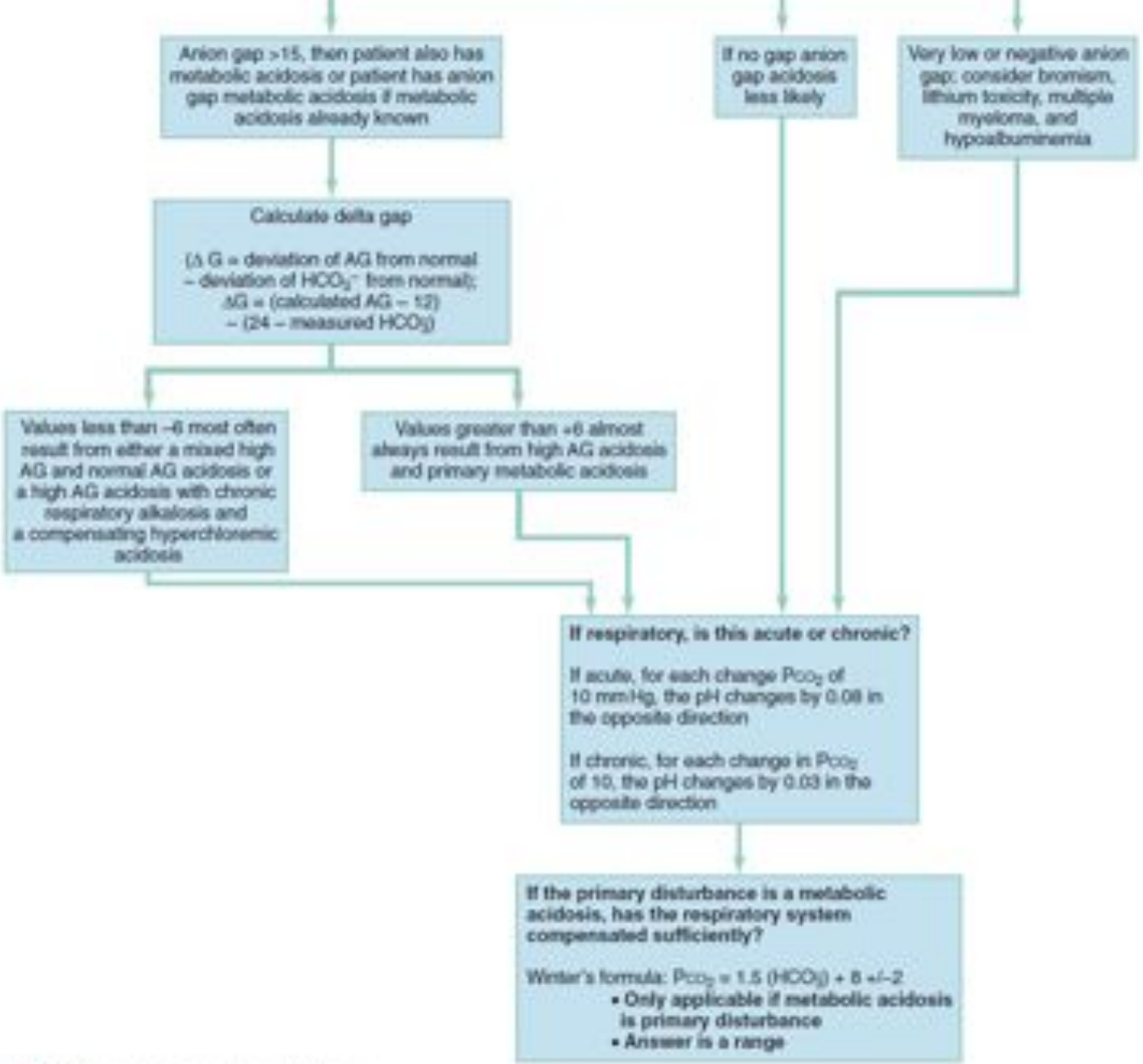

Figure 122-3. Algorithm for acid-base calculation.

Scenario 5

- 22 year-old man, upset that he broke up with his girlfriend, was found confused, next to a bottle of pills. What is the acid-base disorder? What is the ingestion?
  - pH 7.53 Pa_{CO2} 15 HCO_3^- 12 Na^+ 140 Cl^- 108 CO_2 13

Scenario 5

- pH 7.53 Pa_{CO2} 15 HCO_3^- 12 Na^+ 140 Cl^- 108 CO_2 13
- What is the pH?

Scenario 5

- pH 7.53 Pa_{CO_2} 15 HCO_3^- 12 Na^+ 140 Cl^- 108 CO_2 13
- What is the pH?
  - Alkalosis
- What is the Pa_{CO_2} ?

Scenario 5

- pH 7.53 Pa_{CO2} 15 HCO_3^- 12 Na^+ 140 Cl^- 108 CO_2 13
- What is the pH?
  - Alkalosis
- What is the Pa_{CO2} ?
  - Low → respiratory alkalosis
- What is the anion gap?

Scenario 5

- pH 7.53 Pa_{CO2} 15 HCO_3^- 12 Na^+ 140 Cl^- 108 CO_2 13
- What is the pH?
  - Alkalosis
- What is the Pa_{CO2} ?
  - Low → respiratory alkalosis
- What is the anion gap?
  - 19 → Anion gap metabolic acidosis

Scenario 5

- Metabolic acidosis with respiratory alkalosis
- What is the ingestion?

Scenario 5

- Metabolic acidosis with respiratory alkalosis
- What is the ingestion?
- Aspirin

Scenario 6

- 70 year-old man has been vomiting for 2 weeks. HR 140, BP 60/P.
- pH 7.40 Pa_{CO2} 40 HCO_3^- 23 Na^+ 150 Cl^- 87 CO_2 23

Scenario 6

- pH 7.40 Pa_{CO_2} 40 HCO_3^- 23 Na^+ 150 Cl^- 87 CO_2 23
- Normal pH
- What is the anion gap?

Scenario 6

- pH 7.40 Pa_{CO2} 40 HCO_3^- 23 Na^+ 150 Cl^- 87 CO_2 23
- Normal pH
- What is the anion gap?
  - 40 → anion gap metabolic acidosis
- What is the ∆ratio?

∆ratio

- Used in a high anion gap metabolic acidosis to determine of a mixed disorder is present
- Δ AG / Δ HCO_3^- = (AG – 12) / (24 – HCO_3^-)
- A value > 2:1 suggests less of a fall in HCO_3^- than would be expected with a metabolic acidosis → metabolic alkalosis

Scenario 6

- pH 7.40 Pa_{CO_2} 40 HCO_3^- 23 Na^+ 150 Cl^- 87 CO_2 23
- Normal pH
- What is the anion gap?
  - 40 → anion gap metabolic acidosis
- What is the ∆ratio?
  - (40 – 12) / (24 – 23) = 28:1

Scenario 6

- pH 7.40 Pa_{CO_2} 40 HCO_3^- 23 Na^+ 150 Cl^- 87 CO_2 23
- Normal pH
- What is the anion gap?
  - 40 → anion gap metabolic acidosis
- What is the ∆ratio?
  - (40 – 12) / (24 – 23) = 28:1
- This patient has anion gap metabolic acidosis (shock) with metabolic alkalosis (vomiting)

References

- Collings, JL. Rosen's Emergency Medicine. 7th ed. Ch. 122 Acid-Base Disorders. Elsevier 2010.

- Graham, T. Acid-Base Online Tutorial. University of Connecticut. http://fitsweb.uchc.edu/student/selectives/TimurGraham/Welcome.html 2006.

- Smith, SW. Acid-Base Disorders – Hennepin County Medical Center. www.hcmc.org/education /residency/emresidency/AcidBaseLecture2007.ppt 2007.