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Complex Acid Base Disturbances

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Objectives

- Utilize a systematic approach to evaluate acid-base disturbances
- Identify acid-base disturbances
- Identify/recognize the etiology of acid base disorders
- Apply rules of compensation
- Identify/recognize complex (mixed, secondary, tertiary) acid base disorders

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ABG's

pH

??

Base Excess

Anion Gap

Acidosis

?

pH.

$HC03^{-}$

Henderson-Hasselbalch

Alkalosis

Metabolic

PaC02

??

Δ/Δ

SID

Respiratory

Stepwise Analysis

1) Do History and Physical – look for acid-base clues
2) Verify that the lab values are consistent
3) Is pH low, normal or high?
4) Is the primary disturbance metabolic or respiratory? If both are abnormal, pick the one that seems most severe at first glance.
5) Is the disturbance acute or chronic; Have compensatory changes occurred?
6) For Metabolic Acidosis, what is the AG? This will help develop your list of differentials.
7) Is there a secondary or tertiary disturbance present?

H & P Clues

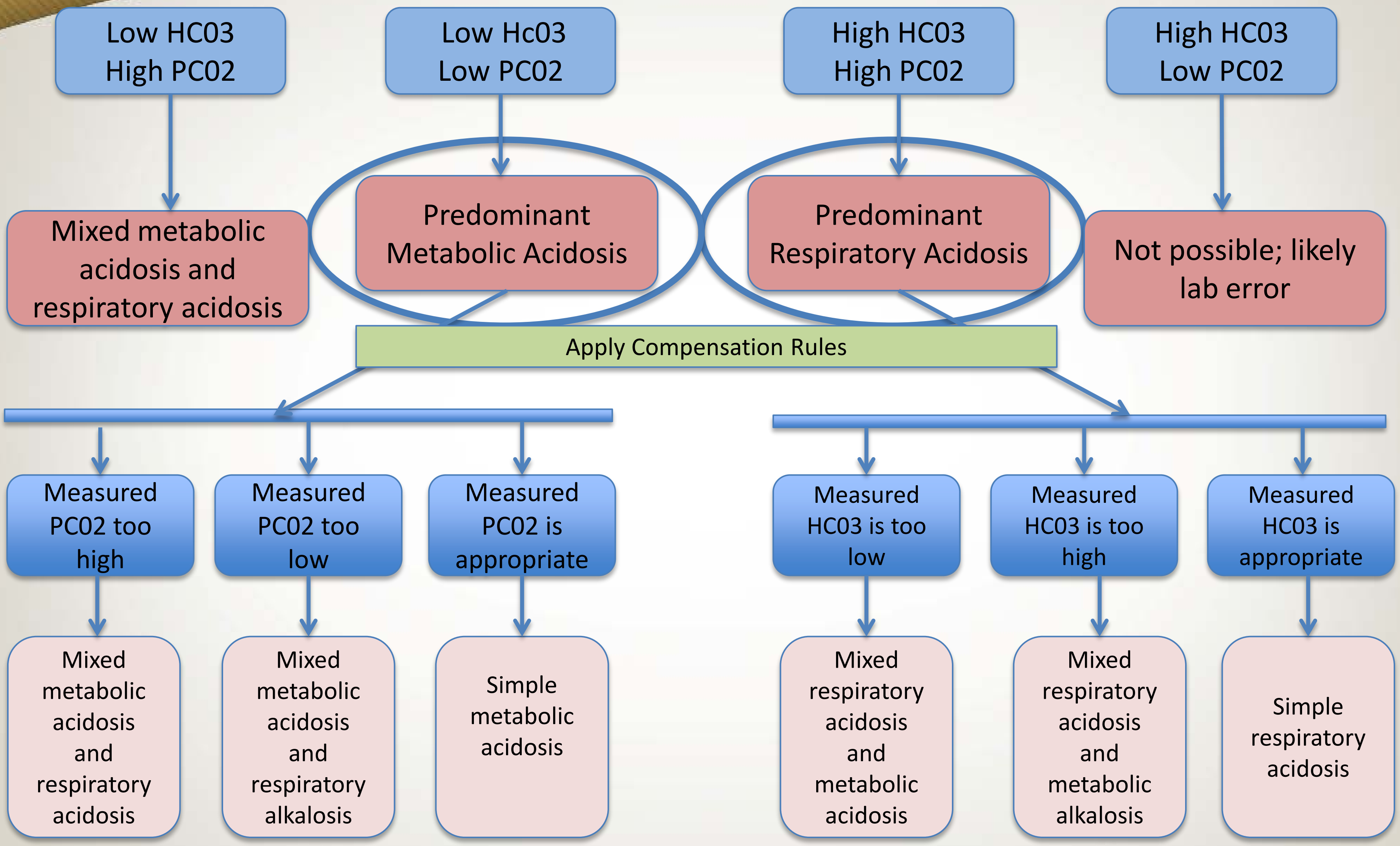
- Vomiting – Metabolic Alkalosis
- History of Diabetes – Metabolic Acidosis
- History of smoking / COPD – Respiratory Acidosis
- History of Liver Disease – Respiratory Alkalosis
- Recent binge drinking – Metabolic Acidosis
- Diarrhea – Metabolic Acidosis
- Tachypnea – Respiratory Alkalosis
- Hypotension – Metabolic Acidosis

- Verify Consistency of Lab Values

  HC03 (ABG) = C02 (venous electrolytes) ±2

- Evaluate the pH – Is it acidotic (< 7.35), normal (7.35 – 7.45) or alkalotic (> 7.45)?
- Is the primary disturbance metabolic or respiratory? If both are abnormal, pick the one that is most severe at first glance.

Acidemia


Low HC03
High PC02
Low Hc03
Low PC02
High HC03
High PC02
High HC03
Low PC02
Mixed metabolic acidosis and respiratory acidosis
Predominant Metabolic Acidosis
Predominant Respiratory Acidosis
Not possible; likely lab error
Apply Compensation Rules
Measured PC02 too high
Measured PC02 too low
Measured PC02 is appropriate
Measured HC03 is too low
Measured HC03 is too high
Measured HC03 is appropriate
Mixed metabolic acidosis and respiratory acidosis
Mixed metabolic acidosis and respiratory alkalosis
Simple metabolic acidosis
Mixed respiratory acidosis and metabolic acidosis
Mixed respiratory acidosis and metabolic alkalosis
Simple respiratory acidosis

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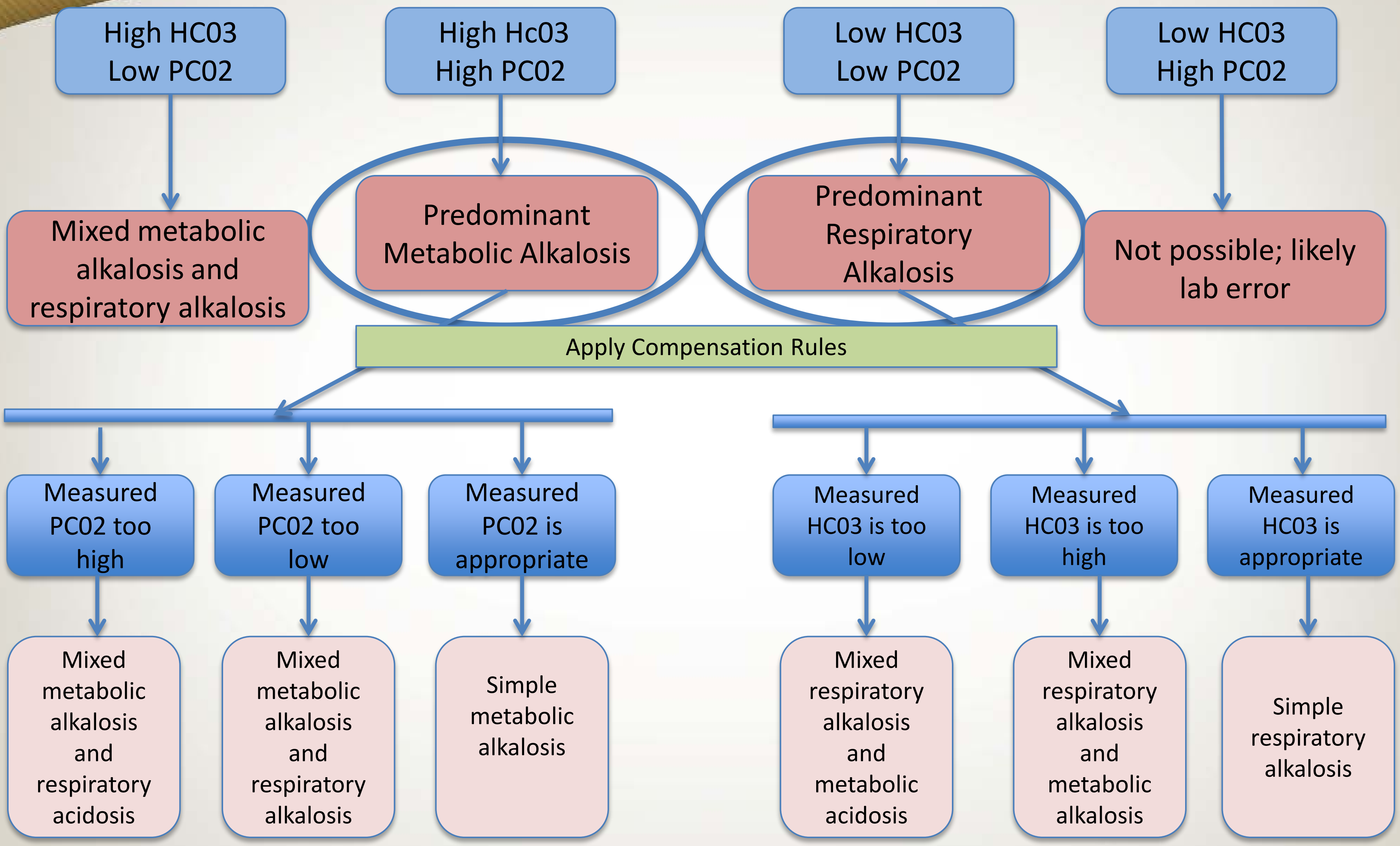
Alkalemia



Metabolic Acidosis

pH < 7.35 with normal or ↓ HC03

- Caused by one of four mechanisms
  - Decreased H^+ excretion - Distal RTA
    - Diminished $NH4^+$ production – Renal failure, Hypoaldosteronism (Type IV RTA)
  - Increased H^+ load – lactate, DKA, toxins, Rhabdo
  - Bicarbonate loss – Diarrhea, Pancreatic Fistula, Ureteral Diversion. Renal bicarb loss (Proximal RTA)
  - Bicarbonate dilution

Marini, John J. and Wheeler, Arthur P. (2010) Critical Care Medicine: The Essentials Fourth Edition. Philadelphia, PA. Lippincott, Williams and Wilkins.

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Metabolic Acidosis

- Threats to life
  - Hemodynamic Instability (↓myocardial contractility, ↓intravascular volume, ↓PVR)
  - Cardiac arrhythmias (hyper or hypokalemia)
  - Ventilatory failure
  - Presence of toxins
  - Nutritional deficiency (B vitamins, Wernicke's)

Halperin, Mitchell L., Kamel, S. and Goldstein, Marc B. (2010) Fluid, Electrolyte and Acid-Base Physiology: A Problem Based Approach, Fourth Edition. Philadelphia, PA. Saunders Elsevier.

Anion Gap

- AG = $(Na^+) – (HC0_3^- + Cl^-)$
- Three clinical applications
  1) Presence or absence of an AG assists in determining the cause of the metabolic acidosis.
  2) The AG is useful in determining the presence of a mixed acid/base disturbance by calculating the Delta Ratio
  3) The AG can be useful in detecting selected disorders that occur with a low, not high AG. (Lithium toxicity, Multiple Myeloma with production of cationic paraproteins)

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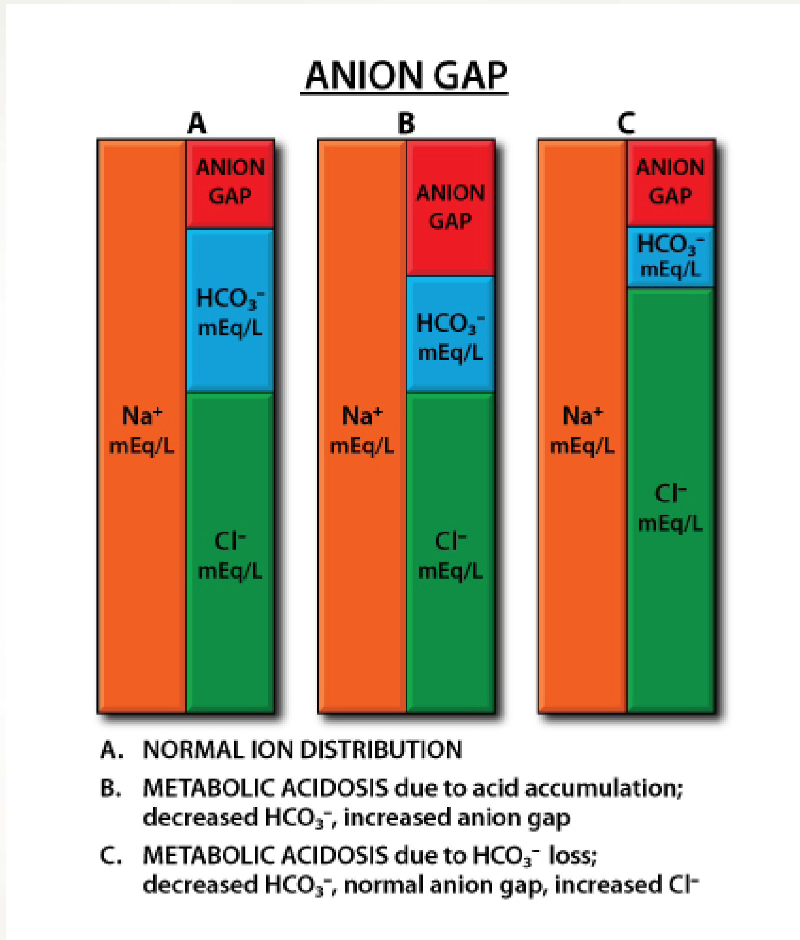
Anion Gap



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Adjusted Anion Gap

- Hypoalbuminemia can mask an increased concentration of gap ions and lowering the value of the AG.
- Adjusted AG =
  AG + 2.5 x (normal albumin g/dL – albumin g/dL)

Example: Pt. albumin 2.0g/dL and AG 15

15 + 2.5 x (4 – 2) = 15 + 5
Adjusted AG = 20

Etiology of Anion Gap Metabolic Acidosis

- Excess endogenous or exogenous acid
- Mudpiles
  - U: Uremia
  - M: Methanol
  - D: Diabetic Ketoacidosis
  - P: Propofol (Paraldehyde)
  - I: Ischemia, INH
  - L: Lactic acidosis
  - E: ETOH ketoacidosis / Ethylene Glycol
  - S: Salicylates / starvation ketoacidosis
- Massive Rhabdomyolysis – release of intracellular phosphate and sulfate

GOLD MARK

G - Glycols – Ethylene glycol and methanol

O - Oxoproline

L - Lactic acidosis (Inadequate perfusion)

D - Lactic acidosis (Increased lactate production or decreased lactate utilization

M - Methanol

A - Aspirin

R - Renal Failure

K - Ketoacidosis

Non-Gap Metabolic Acidosis

- GI Losses of HC03^{+} (Diarrhea, fistulas)
- Renal HC03^{+} loss (Type II RTA)
- Renal dysfunction (Hypoaldosteronism, Type IV RTA)
- Ingestions – ammonium chloride, hyperalimentation fluids

- Dilutional metabolic acidosis
  - Usually due to administration of large volume saline

A Word About NaHC03

- Direct treatment of acute metabolic acidosis with NaHC03 is **not** indicated, **unless**:
  - pH < 7.10
  - Overt physiologic compromise is present
  - Excessive work of breathing is required to maintain pH > 7.2
- NaHC03 is not indicated in DKA, even with pH < 7.10 due to the risks of developing rebound alkalosis or exacerbating hyperosmolarity.

Metabolic Alkalosis

- pH > 7.45 with normal or ↑HC03
  1) Anion loss
     - Chloride responsive
     - Chloride unresponsive
     - Determined by measuring urine electrolytes
  2) Cation gain
- Correction of long-standing respiratory acidosis with institution of invasive or non-invasive mechanical ventilation
- Rarely, due to regulation of K^+ by exchanging H^+ ions for K^+ in tissues and kidneys resulting in H^+wasting (Cushings, steroid therapy)

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Metabolic Alkalosis

Chloride Responsive	Chloride Unresponsive
Urine sodium low (<20)	Urine sodium > 20
Gastric loss (vomiting, NG suction)	Primary hyperaldosteronism
Urinary loss (diuresis, mannitol)	Corticosteroids
Renal response to hypercapnea (Cl^- loss at renal tubule as $HC03^+$ is generated)	Correction of long-standing respiratory acidosis (institution of invasive or non-invasive mechanical ventilation)
	Hypokalemia

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Respiratory Acidosis

- pH ↓ 7.35 with normal or ↑PaC02
- Decreased ventilation
  - Acute
    - Exacerbation of severe asthma
    - PNA
    - Pulmonary edema
    - Post cardiac-arrest
    - Drug overdose
    - Administration of 02 in setting of chronic hypercapnea.
  - Chronic: chronic obstructive lung diseases

Symptoms of Respiratory Acidosis

- Headache
- Blurred vision
- Restlessness
- Anxiety
- Tremors
- Asterixis
- Delirium
- Somnolence
- Hypotension when pH falls below 7.10

Chronic Respiratory Acidosis

Compensated	Uncompensated
Elevated PaC02	Elevated PaC02
Near Normal pH	pH < 7.35

Respiratory Alkalosis

- pH ↑ 7.45 with normal or ↓ PaC02
- Increased ventilation
  - CNS Disturbances
  - Pain
  - Inappropriate mechanical ventilation
  - Drugs (salicylates, catecholamines, theophylline)
  - Hypoxemia
  - Liver Disease
  - Pulmonary receptor stimulation / ↓ lung compliance (PNA, pulmonary embolism, asthma, pulmonary fibrosis, pulmonary edema)
  - Pregnancy

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Respiratory Alkalosis

- Symptoms
  - Parasthesias, tetany, tremor
  - Chest pain, circumoral parasthesia, lightheadedness
  - anxiety

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Compensation Basics

- Compensatory changes are dependent upon normal function of the compensating system
- Most compensation is incomplete
- Lack of adequate compensation may indicate the presence of a co-existing secondary disorder
- Different compensatory formulas are applied, depending upon the primary disturbance
- Humans have good buffering systems for acidosis but a reduced ability to buffer alkalosis

Respiratory Compensation

- PC02 changes in the same direction as the serum HC03
  - PC02 ↓ in metabolic acidosis
  - PC02 ↑ in metabolic alkalosis
- Respiratory compensation decreases the change in ratio of HC03:PC02, and therefore in the pH.
- Rapid onset of response, within 30 minutes
- Complete within 12-24 hours
- Respiratory compensation can occur to a physiologic max of PaC02 50 to 55; higher PaC02 in this situation indicates a concominant Respiratory Acidosis

Emmett, M., Sterns, Richard H. and Forman, John P. (2013) Simple and mixed acid-base disorders. http://www.uptodate.com.proxy.library.vanderbilt.edu/contents/simple-and-mixed-acid-base-disorders?detectedLanguage=en&source=search_result&search=winters+formula&selectedTitle=1~2&provider=noProvider#H365263262 8/7/2013

Renal Compensation

- HC03 changes in the same direction as the PC02
  - HC03 ↑ in respiratory acidosis due to increased H^+ secretion
  - HCO3 ↓ in respiratory alkalosis due to decreased H^+ secretion and urinary HC03 loss
- Slower onset of compensation, within hours
- Completion takes days to weeks for maximal effect
- Expected findings differ in acute (little or no renal compensation) and chronic (full renal compensation) respiratory acid-base disorders.

Emmett, M., Sterns, Richard H. and Forman, John P. (2013) Simple and mixed acid-base disorders. http://www.uptodate.com.proxy.library.vanderbilt.edu/contents/simple-and-mixed-acid-base-disorders?detectedLanguage=en&source=search_result&search=winters+formula&selectedTitle=1~2&provider=noProvider#H365263262 8/7/2013

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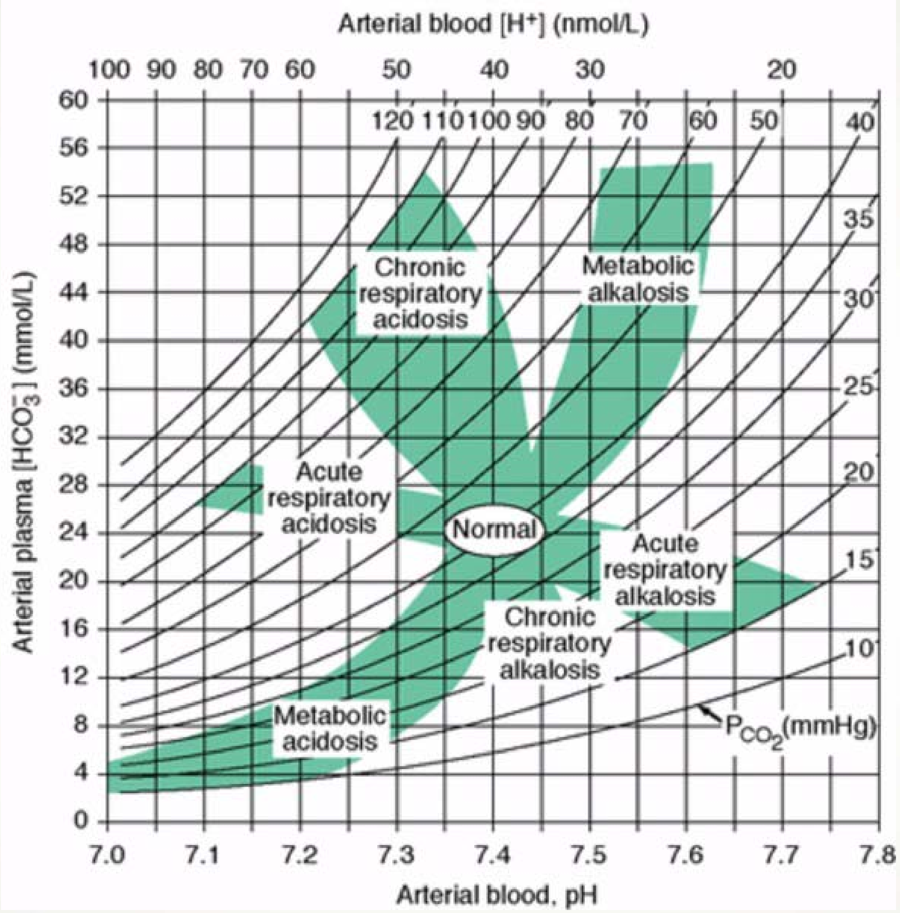
Acid-Base Nomogram



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Expected Compensation for Acid-Base Disorders

Primary Disorder	Primary Change	Compensatory Change	Expected Compensation
Metabolic Acidosis	↓ $HC03^-$	↓PaC02	ΔPaC02 = 1.2 Δ $HC03^-$
Metabolic Alkalosis	↑$HC03^-$	↑PaC02	ΔPaC02 = 0.9 Δ $HC03^-$
Respiratory Acidosis Acute Chronic	↑PaC02	↑$HC03^-$	 Δ$HC03^-$ = 0.10 Δ PaC02 Δ$HC03^-$ = 0.35 Δ PaC02
Respiratory Alkalosis Acute Chronic	↓PaC02	↓ $HC03^-$	 Δ$HC03^-$ = 0.2 Δ PaC02 Δ$HC03^-$ = 0.5 Δ PaC02

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Δ PaC02 = 1.2 x Δ HC03

Δ HC03 = 24 (optimal) – measured HC03

Δ PaC02 = 40 (optimal) – calculated, expected change in PaC02

- **pH 7.22 / 30 / 10**

  Δ HC03 = 24 – 10 = 14

  1.2 × 14 = 16.8

  Δ PaC02 = 40 – 16.8 = 23.2

  Expected PaCO2 = 23.2mmHg.

- Conclusion – Not completely compensated ; because PaC02 should be 23 but it is 30.

Compensation for Metabolic Acidosis

1) Δ PaC02 = 1.2 Δ HC03

2) **pH = last two digits of PaC02**
   pH 7.25 → PaC02 25

3) **Winter's Formula - Estimates the expected PCO2**
   (1.5 x HC03) + 8 = PaC02 ± 2

Winter's Formula *

(1.5 x HC03) + 8 = PaC02 ± 2

- **ABG: 7.22 / 30 / 10**
- Na 139, K 4.0, Cl 90, C02 10

(1.5 x 10) + 8 = 23

23 ± 2 is < measured PaC02 (30)

Expected PC02 = 23

Conclusion – Not completely compensated

Compensation Pearls for Chronic Metabolic Acidosis

- If PaC02 is > expected, then the time for respiratory compensation has been too short; or a respiratory acidosis is also present.
- If the PaC02 is < expected, then a concominant respiratory alkalosis is also present

Compensation Formulas for Metabolic Alkalosis

1) $\Delta PaC02 = 0.9\ \Delta\ HC03$

2) PaC02 ↑ 0.7mmHg for every 1mEq elevation in the serum HC03 concentration

3) PaC02 = 40 + .7 (measured HC03 – normal HC03)

4) **PaC02 = (0.9 x HC03) + 15**

PaC02 = (0.9 x HC03) + 15

ABG 7.56 / 44 / 70 / 38

- PaC02 = (0.9 x HC03) + 15

  0.9 x 38 + 15 = 49.2

Expected PaC02 = 49.2

Conclusion - Not completely compensated

Compensatory Formulas for Respiratory Acidosis

- Acute
  1) HC03 ↑ 1 / 10mm Hg increase in PaC02
  2) ΔHC03 = 0.10 Δ PaC02
  3) **HC03 = (PC02 – 40 / 10) + 24**
- Chronic
  1) HC03 ↑ 3.5 / 10mm Hg increase in PaC02
  2) ΔHC03 = 0.35 Δ PaC02
  3) **HC03 = (PC02 – 40/ 5) + 24**

Acute
HC03 = (PC02 – 40 / 10) + 24

ABG: 7.22 / 70 / 25

HC03 = (PC02 – 40 / 10) + 24

70-40 = 30

30 /10 = 3

Expected HC03 is 3 + 24 = 27

Conclusion – Incomplete compensation

Chronic
HC03 = (PC02 – 40 / 5) + 24

ABG: 7.30 / 90 / 38

HC03 = (PC02 – 40 / 5) + 24

90 – 40 = 50

50 / 5 = 10

Expected HC02 is 10 + 24 = 34

Conclusion – Incomplete compensation

Compensatory Formula for Respiratory Alkalosis

- Acute
  1) HC03 ↓ 2 / 10 mmHg decrease in PC02
  2) Δ HC03 = 0.20 Δ PaC02
  3) **HC03 = 24 - (40 – PaC02 / 5)**
- Chronic
  1) HC03 ↓ 5 / 10 mmHg decrease in PC02
  2) Δ HC03 = 0.5 Δ PaC02
  3) **HC03 = 24 - (40 – PaC02 /2)**

Acute
HC03 = 24 - (40 – PaC02 / 5)

ABG: 7.52 / 28 / 24

HC03 = (40 – PaC02) / 5

40 – 28 = 12

12 / 5 = 2.4 + 24 = 26.4

Expected HC03

Conclusion – Incomplete compensation

Chronic
HC03 = 24 - (40 – PaC02 /2)

ABG 7.44 / 22 / 18

- HC03 = 24 - (40 – PaC02 /2)

 40 – 22 / 2 = 9

 24 – 9 = 15

Expected HC03 15

Conclusion – Incomplete compensation

Easy Compensation Formulas

Primary Disorder	Compensatory Change	Expected Compensation
Metabolic Acidosis	↓PaC02	(1.5 x HC03) + 8 = PaC02 ±2
Metabolic Alkalosis	↑PaC02	PaC02 = (0.9 x HC03) + 15
Respiratory Acidosis Acute Chronic	↑HC03⁻	 HC03 = (PC02 – 40 / 10) + 24 HC03 = (PC02 – 40 / 5) + 24
Respiratory Alkalosis Acute Chronic	↓ HC03⁻	 HC03 = 24 - (40 – PaC02 / 5) HC03 = 24 - (40 – PaC02 /2)

Finding Mixed Acid-base Disturbances

1) PC02 <u>and</u> HC03 both adding to the pH change
   → mixed Acid-base disorder is present
2) Calculate corrected HC03 = HC03 + Δ AG
   Corrected HC03 > 28 → Alkalosis
   Corrected HC03 < 20 → Acidosis
3) **Calculate the Delta Ratio (Δ / Δ)**
   Δ Anion Gap/ Δ $HC03^-$

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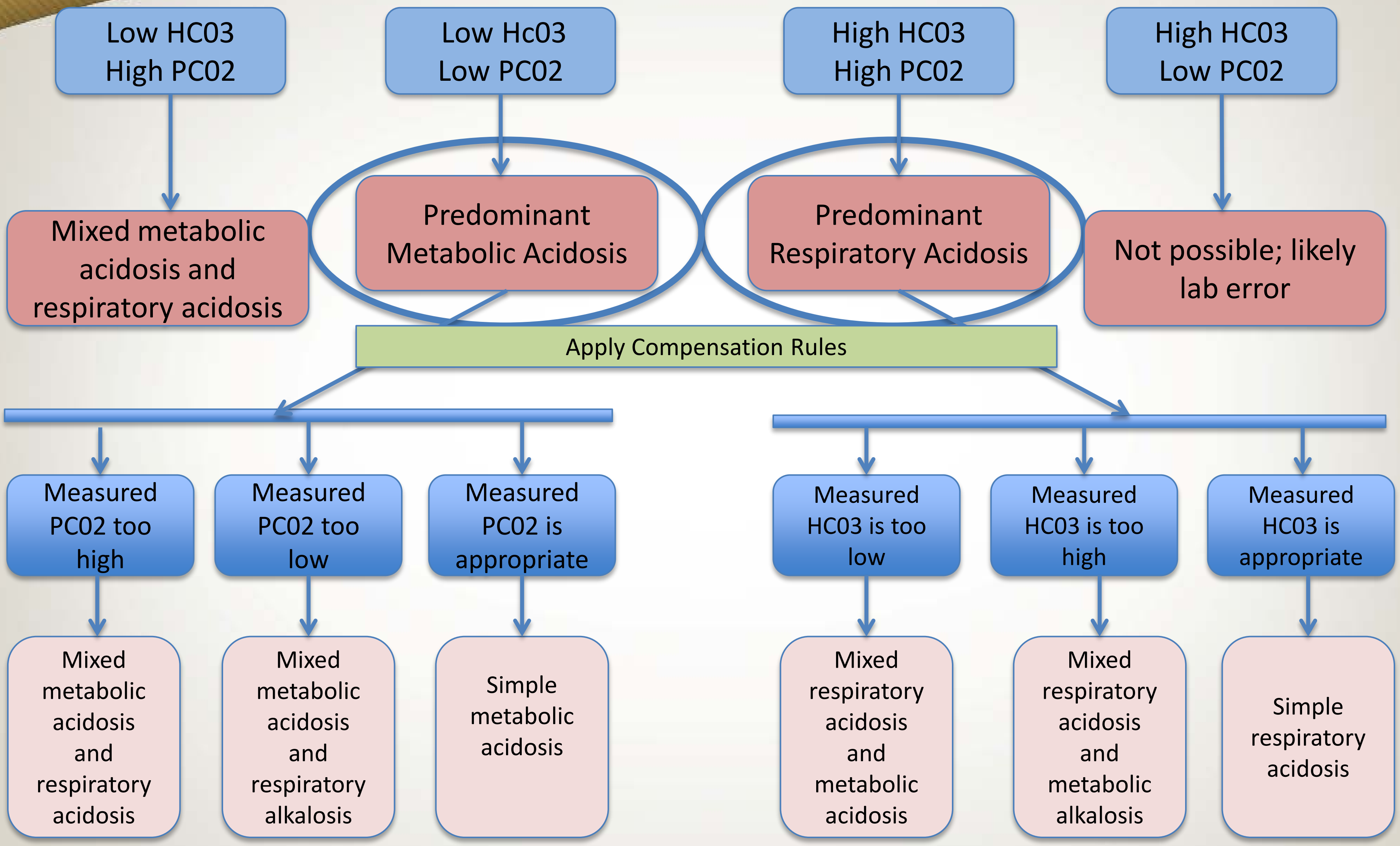
Acidemia



Mixed Metabolic Acidosis Pearls

If the PaC02 > expected HC03$^-$, then the time for respiratory compensation has been too short; or a respiratory acidosis is also present.

If the PaC02 < expected HC03$^-$, then a concominant respiratory alkalosis is also present

Delta Ratio

- Delta Ratio = Δ Anion Gap/ Δ HC03⁻

  Δ / Δ = 1-2 → uncomplicated high AG metabolic acidosis

  Δ / Δ < 1 → combined high AG metabolic acidosis and normal AG metabolic acidosis

  Δ / Δ > 2 → combined high AG metabolic acidosis and concurrent metabolic alkalosis

Delta / Delta
ΔAG / ΔHC03⁻

1) ABG: 7.26 / 15 / 14

BMP: Na 130, Cl 90, C02 15, AG = 25

25 - 10 / 24-15 = 15/9 = 1.66

Δ/Δ 1-2 : Uncomplicated high AG metabolic Acidosis

2) ABG: 7.22 / 30 / 10

BMP: Na 139, Cl 110, C02 10, AG = 19

19 – 10 / 24 – 10 = 9/14 = 0.64

Δ/Δ : Combined high AG metabolic acidosis <u>and</u> normal AG metabolic acidosis

Summary of Key Points

- Systematic approach, use H&P clues
- Pick the most severe-appearing abnormality and start there
- The flow charts are your friends
- Apply compensation formulas – find the formulas that are easiest for you
- Use Delta / Delta to detect mixed disturbances

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References

Brixey, Anu. MICU ACNP lecture, Spring 2010.

Emmett, Michael. Simple and mixed acid-base disorders. UpToDate. http://www.uptodate.com.proxy.library.vanderbilt.edu/contents/simple-and-mixed-acid-base-disorders?detectedLanguage=en&source=search_result&search=acid+base&selectedTitle=1%7E150&provider=noProvider (August 18, 2013)

Halperin, Mitchell L., Kamel, Kamel S. and Goldstein, Marc B. (2010) Fluid, Electrolyte and Acid-Base Physiology: A Problem Based Approach, Fourth Edition. Philadelphia, PA. Saunders Elsevier.

Kellum, John A. (2007) Disorders of Acid Base. Critical Care Medicine. Vol 35, No. 11 2630-2636)

Marini, J.J. & Wheeler, A.W. (2010) Critical Care Medicine: The Essentials, Fourth Edition. Philadelphia, PA. Lippincott, Williams & Wilkins.

Newman, John. MICU ACNP Lecture, Spring 2010.

Szerlip, Harold M. CHEST Critical Care Board Review. August 25, 2013.

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References

http://fitsweb.uchc.edu/student/selectives/TimurGraham/Compensatory_responses_metabolic_acidosis.html (August 18, 2013)

http://courses.washington.edu/med610/abg/popup_exampleSet4.html (August 18, 2013)

http://www.globalrph.com/abg_analysis.htm (August 18, 2013)

http://www.scribd.com/doc/12085262/Acid-Base-Handout-Student (August 18, 2013)